JOURNAL OF AGRICULTURAL RESEARCH

VOL. XXV WASHINGTON, D. C., JULY 14, 1923 NO. 2

TRANSMISSION, VARIATION, AND CONTROL OF CERTAIN DEGENERATION DISEASES OF IRISH POTATOES[1]

By E. S. SCHULTZ, *Pathologist, Cotton, Truck, and Forage Crop Disease Investigations, Bureau of Plant Industry, United States Department of Agriculture,* and DONALD FOLSOM, *Plant Pathologist, Maine Agricultural Experiment Station*

INTRODUCTION

Progress in solving the well-known problem of degeneration in the Irish potato, *Solanum tuberosum* L., has been comparatively rapid during the last decade. With this progress the apparent complexity of the problem has increased. Consequently the results of many investigators are needed and frequent reports from the various workers in this field are desirable.

Of the many phases of the problem in question, the writers have restricted their efforts largely to those of the transmission, variation, and control of certain diseases causing degeneration. This paper both confirms the results of workers in other regions and also discloses hitherto unreported principles that must be respected if control is to be attained ultimately.

TERMS AND TECHNIC USED IN THESE STUDIES

As pointed out by Quanjer (*39, p. 127*),[2] it is desirable that those working with degeneration diseases agree as to the meaning of terms employed. As the same author also points out in referring to the English use of the term "leaf curl," this agreement has not been realized. The varietal modification of symptoms described by Quanjer (*39, p. 130*), by Murphy (*29, p. 34*), and by the writers in this paper, makes it difficult to reach such an agreement in the use of terms until at least the same variety is used by different investigators for a study of the various diseases. Under this state of affairs it seems necessary first to define the terms to be used in this paper. Certain general methods of technic also will be described here to obviate repetition.

Degeneration diseases of potato are here considered to be those transmissible or infectious diseases which are perpetuated indefinitely by vegetative growth and propagation, and of which no cause, either organic or inorganic, has been identified and demonstrated. They include maladies of which the etiology is not fully understood. Although intracellular

[1] Accepted for publication May 2, 1923. This paper is based upon investigations carried on as a cooperative project between the Office of Cotton, Truck, and Forage Crop Disease Investigations of the Bureau of Plant Industry, U. S. Department of Agriculture, and the Department of Plant Pathology of the Maine Agricultural Experiment Station. Unless otherwise indicated, the work was performed in northeastern Maine in the vicinity of Presque Isle. The order of arrangement of the authors' names is not intended to indicate that one cooperating institution contributed more than the other to the results.

[2] Reference is made by number (italic) to "Literature cited," p. 115-117.

amoeboid bodies have been found associated with mosaic of tobacco (1, 34), with mosaic of sugar cane (26), with mosaic of corn (22), with mosaic of *Hippeastrum equestre* (23), with mosaic of *Hippeastrum johnsonii* (2 and with rosette disease of wheat (24), nevertheless, the causal relation of these bodies and organisms to those diseases remains to be demonstrated. For convenience this unknown cause, which seems to be associated with the plant juice, will be referred to here, as elsewhere, as a contagium or a virus. Degeneration diseases are further characterized generally by dwarfing and chlorosis, and by the absence of the first symptoms from foliage that has attained complete growth before the introduction of the virus.

In the absence of definite information on the exact causes of degeneration diseases of plants, it is necessary to define such diseases, both as a class and as individuals, entirely in terms of behavior and symptoms. A number of characteristics are considered by the writers and others as being elementary "unit symptoms" of degeneration diseases of the potato. Dwarfing consists essentially of reduction in size of parts (Pl. 2, A, 2) rather than in their number, although both may occur together. *The supporting parts of the shoots and leaves are reduced in length and thickness. The leaf blades are reduced in area, possibly only apparently so sometimes when wrinkling or ruffling is present. Spindliness is lateral dwarfing, resulting in stems or tubers being abnormally slender (Pl. 8, A, 2, C, 1, 2).* Chlorosis is a yellowing or *paleness that affects the leaf blades and is assumed as being diffuse* unless designated as mottling. Mottling is a localized chlorosis consisting of spotting of the leaf blades by light green areas, which may or may not occur in contact with the larger veins, and which vary in shape and degree of paleness. These discolored spots are punctate, elongate, circular, angular, and irregular. They vary from a barely discernible fading of the green to an almost pure yellow, often in the same spot. They seldom exceed a few millimeters in any dimension, and their distinctness of outline differs, usually in proportion to the degree of discoloration. They are more readily seen in diffused light than in direct sunlight. Wrinkling is an abnormal unevenness of the leaf-blade surface due to depressions and prominences not arranged in any uniform manner as with rugosity (Pl. 1, A, 1, 2). Rugosity differs from wrinkling in having depressions only at the veins and in having the prominences of uniform height (Pl. 3, C; 4, A, 1). Ruffling is an abnormal unevenness of the leaf-blade surface caused by ridges that develop or become more pronounced with passage from the midrib to the lateral margins, resulting in waviness of the margin (Pl. 1, A, 1, 2). Curling is an abnormal bending of the leaf blade downward along the main vein (Pl. 3, A). Rolling is an upward curving of the sides of each leaflet with the midrib at the bottom of the trough thus formed (Pl. 6, C, 2). Uprightness may appear in both leaves and stems but is assumed to be in the latter alone unless otherwise stated (Pl. 10, B, 2, C, center). It is characteristic of normal plants in most varieties when small and probably in diseased plants is often due to dwarfing. Rigidity may affect either stems or petioles, or both; brittleness may do the same (Pl. 6, A, 2, B, 1). Necrosis is the premature death of tissues accompanied and manifested by their turning brown. It may appear as spot necrosis or spotting (Pl. 5, B), with brown flecks of leaf blade usually more conspicuous on the upper surface; or, as streak necrosis or streaking, with brown streaks first, most evident on the lower surface of the

f veins (Pl. 5, B) but sometimes also apparent on the upper leaf face, stems, and petioles; or, it may appear as marginal necrosis or rning, beginning at the margin and progressing inward. Streaking y spread out into the parenchyma as spotting or burning. Leaf opping concerns entire leaves, usually the lowest first, and then progressively higher ones. It may begin with a collapse of the green petioles, lowed by wilting and finally by necrosis of the petioles and blades. emature death usually is preceded by leaf dropping and necrosis and ally involves the whole stem and shoot.

The preceding is concerned with isolated unit symptoms. Certain quently occurring groupings of these unit symptoms have been conlered as indicating the presence of certain viruses and have been designted by various descriptive terms such as mosaic (*32, 45*), mosaic arf (*21; 32, fig. 29*), curly dwarf (*32, 38*), streak (*5, p. 50; 33*), f roll (*32, 41*), and others. These symptom-complexes will be conlered later in this paper, except that it may be stated here that a deneration disease is considered to be of the mosaic type if there is ottling and abnormal unevenness of the leaf surface.

The writers have performed inoculation, or the introduction of material oculum) from a diseased plant into a healthy one, by means of several ethods. Tuber grafts have been made by keeping in contact the cut rfaces of split tubers. Stalk grafts have been made by splitting the althy stalk and inserting the wedge-shaped base of a diseased scion d fastening with cord and water-impermeable tape. Leaf-mutilation oculation consists of bruising the healthy leaves with the fingers or palms d applying to the spongy mass of mutilated leaf tissue juice that has en expressed from a diseased plant. This may be repeated at intervals several days. Capillary-tube inoculation consists of inserting small glass tubes, containing the inoculum, into the stalk. Aphids have been transferred from the diseased to the healthy plant growing in separate cages or have been both transferred and allowed to disperse with the diseased and healthy plants in the same cage. In the latter case there was root contact, which has also been tried with aphids absent. Natural inoculation is effected by aphids.

A control to an inoculated plant is reliable only when in the same tuber unit; that is, in the group of plants or hills growing from the separated parts (seed pieces or sets) of the same tuber. The members of tuber unit are sometimes separated and planted in several places or cages. Current-season symptoms are those appearing in the same season in which inoculation occurs, in contrast to those following both inoculation and tuber perpetuation of the disease. These two classes of symptoms, differing only as to the immediate origin of infection, have been designated respectively as primary and secondary by Quanjer (*38, p. 36; 9, p. 130*), and respectively as secondary and primary by Edgerton (*12, p. 7*) following the nomenclature of sugar-cane mosaic. The incubation period is the length of time between inoculation and the appearance of current-season symptoms. If current-season symptoms are absent or if they appear in plants under cages or in other abnormal conditions, it is desirable to observe the second generation following tuber perpetuation. If they appear in normal conditions in a high percentage of the inoculated plants and not in the controls, uncontrolled natural transmission in the field, presumably by insects, will sometimes cause late-season infection of the controls so that observation after tuber perpetuation is of less value than that made before. The second-generation progeny of a hill will be

called a hill lot. Hill lots from the same tuber unit are the beginning a tuber-unit strain. A hill lot usually is planted so that it consists consecutive undivided tuber units, in order that comparison betwe tubers may be made more easily.

TRANSMISSION AND DIAGNOSIS IN THE GREEN MOUNTAIN VARIETY

A given degeneration disease often differs with the variety of potato, so that the data first presented will be limited to the variety with wh the writers are most familiar. In this variety, the Green Mounta several diseases have been distinguished, occurring both singly and combinations. They will be considered first separately and then co paratively, with final consideration of the question of combinations.

MILD MOSAIC

Mosaic of potatoes was first described in the literature by W. A. Ort (*32, p. 42; 29, p. 59*) although Quanjer claims to be the first to di tinguish it (*39, p. 128*):

> Gradually I learned to distinguish the leaf-roll type, and another type which r minded me of the mosaic disease of tobacco ...... Afterwards Danish and Ameri investigators also began to distinguish mosaic.

The term "mosaic" will be used here as covering several types diseases all characterized in common by mottling and wrinkling. T term "mild mosaic" has been used by Tolaas (*49, p. 10*) and is now us by the writers as equivalent to the slight, slight plus, and, in part least, the medium stages of mosaic as previously described by the (*40, p. 316*). The characteristic symptoms consist of slight dwarfin distinct mottling, wrinkling, and some ruffling (Pl. 1, B, 1, C,2). A will be shown later, it is more easily transmitted than leaf roll and is le easily transmitted than rugose mosaic and streak. The tuber sympto are a general average reduction in size.

CONTACT INOCULATIONS

As reported previously (*40, p. 319*), tuber-graft inoculation may resu in infection with current-season symptoms. Stalk grafts may do th same (*45, p. 251–53; 40, p. 319*). Temporary contact of healthy an mosaic seed pieces all cut with the same knife did not cause apprecia infection (*40, p. 332–33*). Contact of uncut tubers in storage probab results in no transmission. Several stocks with a small percentage mosaic have been used to furnish seed for greenhouse experiments car in the winter and also for field experiments after winter storage, but di not have a higher percentage of incidence in the field after the longe period of contact of the tubers in storage.

Contact of healthy and mosaic shoots was not followed by infectio in greenhouse experiments (*45, p. 264–65*) except after aphids had fe upon these shoots.

Contact of both shoots and roots in the greenhouse (*40, p. 333*) was not followed, during three months of active growth subsequent t establishment of contact, by any mosaic symptoms. This was in marke contrast with results in a contemporary experiment wherein plan that started to grow 2 weeks later and that were harvested at the sam

e showed symptoms from 4 to 10 weeks before harvest as the effect aphid transmission.

Complete contact inoculation of 10 hills inside of 5 field cages in 1919 s accompanied by transmission of mosaic in the first generation only one cage where aphids accidentally gained access (*40, p. 333–34*).

A greenhouse experiment was performed in the winter of 1919–20 h aphids excluded by insect cages and with two healthy plants growing the same pots with mosaic ones. The tubers when dug remained ached to the rhizomes and those of the healthy plants produced althy progeny.

In field insect cages in 1920, healthy hills grown with roots, shoots, or h in contact with mosaic hills (Table I) displayed no symptoms and d healthy progeny, except when aphids were present.

TABLE I.—*Mild mosaic inoculations of caged Green Mountains in 1920 (Presque Isle, Me.)*

Inoculation.			Progeny, 1921.	
ries.	Method.	Hills.	Tuber units.	Mosaic.
				Per cent.
1	Aphids, flea beetles, and full contact (of roots and shoots)	[a] 5	12	83
2	Flea beetles and full contact	[a] 1	8	0
3	Full contact (controls to Series 1, 2)	[a] 6	20	0
4	Root contact	[a] 12	47	0
5	Flea beetles and shoot contact	[b] 6	24	0
6	Flea beetles	[b] 6	26	0
7	Shoot contact	[b] 6	18	0

Six 4-hill tuber units each represented in Series 1 or 2, 3, and 4.
Six 3-hill tuber units each equally represented in Series 5, 6, and 7.

During the winter of 1921 and 1922, in a greenhouse experiment at ashington, D. C., 15 healthy tubers were split; one half of each tuber as planted in an 8-inch pot not in contact with a mosaic plant, the other lf was planted in a 10-inch pot with a tuber half taken from a mild osaic potato vine. Ten of the healthy half tubers were planted in ntact with the mosaic seed pieces but not grafted; the remaining 5 were anted 6 inches from the mosaic seed pieces. Nine of the mosaic seed eces represented the Bliss Triumph variety, while the remaining six osaic tuber halves represented the Green Mountain variety.

The fifteen 10-inch pots were kept under aphid-proof cages from ecember 30, 1921, when the tubers were planted, until April 11, 1922, hen they were harvested. The fifteen 8-inch control pots with the ngle healthy half-tuber seed pieces were kept uncaged in the same eenhouse as the caged lots. Three examinations for aphids during e course of this experiment did not disclose a single aphid within the ages. These observations also revealed that every vine from the 15 osaic seed pieces showed distinct mild mosaic mottling, and that the ines from the 15 healthy seed pieces remained free from mosaic mottling ntil they were harvested April 11, 1922, when the majority of the plants owed distinct signs of maturity. The second-generation plants from e healthy seed pieces like the first generation also failed to show any gns of mosaic mottling, while under the same conditions distinct

mosaic mottling appeared on the vines from mosaic seed pieces. T test confirms earlier, well-controlled experiments, showing that root vine contact alone do not result in mosaic transmission.

Further data on contact inoculation will be given when conside intervarietal transmission.

JUICE-TRANSFER INOCULATIONS

Aphids are a natural means of transmission and when of cosmop itan species like potato aphids, *Macrosiphum solanifolii* Ashm., spinach aphids, *Myzus persicae* Sulz., are usually readily available capable of being multiplied to sufficient numbers under control co tions, at least for a limited number of experiments. The difficulty w aphids is chiefly one of supplying the proper control conditions inoculations on a large number of plants in the open field. Aphids cause uncertainty regarding the interpretation of the presence or abse of certain symptoms, inasmuch as they often produce dwarfing, mottl chlorosis, wrinkling, streaking, and complete necrosis directly even wh nonvirulent, especially if abundant, and as, on the other hand, they m be influenced by certain conditions so that they do not accept a n host readily. Therefore an artificial method of transmission if effect may be preferable to the use of aphids, because of greater ease of app cation to a large number of plants, because of the absence of dir inoculation injury on the new growth, and because of the greater u formity of treatment. It also introduces no disturbing factor into aphid-free field or greenhouse as would be done by the introduction uncaged aphids or of aphid cages. It sometimes is necessary wh aphids fail to increase to sufficient numbers.

While each method has advantages, both should be used, especia with such virus diseases as have been transmitted experimentally w neither or with only one. As an artificial method of inoculation, tub grafting is handicapped by the uncertainty as to how many new d eases were acquired by the parent vines while apparently healthy, wh stem grafts in the open field often fail because of hot, dry weath As a result, the leaf-mutilation method (p. 45) has been used exte sively by the writers.

It has been reported (*45, p. 253–54; 40, p. 320–26*) that mosaic c be transmitted by leaf-mutilation inoculation, but there is some unce tainty as to what types of mosaic were involved. The type diagnos as mild mosaic has since been used.

Such inoculations in 1921, in the open field, and during the preced winter, were intervarietal and will be described later. Some were pe formed and repeated inside of insect cages within the Green Mount variety, upon 6 hills in as many tuber units. Two hills showed curre season symptoms and their progeny, three and four tuber units, resp tively, were mild mosaic. The other 4 inoculated hills and 18 oth caged hills in the same tuber units, were all healthy in both generatio originating from healthy control hills caged in 1920. Six of the other hills were inoculated with the capillary-tube method (p. 45) a 12 were controls.

On December 19, 1921, in the greenhouse at Washington, D. C., eig potato plants, from 3 to 8 cm. in height, were treated with juice from mild mosaic vine by leaf-mutilation inoculation. Four of these pla were then kept in a moist chamber for 24 hours while the remain were outside of a moist chamber. By the end of four weeks,

saic appeared on the top leaves on one of the plants. At this time vines varied from 30 to 40 cm. in height. On the vines in the ond generation, however, this and two additional cases developed mild saic. These three mottled vines—that is, 37 per cent of the treated nts—included all the plants, except one, kept in a moist chamber 24 hours after treatment. None of the inoculations outside of moist mbers were effective. The three successful inoculations were permed on three of the four plants that were 5 cm. or more high when culated.

On December 21, 1921, eight healthy plants were treated as those culated on December 19 had been, with the exception that only two the plants were kept in moist chambers until 24 hours after inoculan. One of these plants developed mild mosaic before harvest, and the second generation the other showed mild mosaic. Hence only two vines which were placed in moist chambers developed mosaic. each of the foregoing series only a single inoculation was performed.

Leaf-mutilation inoculation (not repeated) with mild mosaic had no ects when made in the Orono (Me.) greenhouse in the winter of 1921–22, 10 hills from five tuber units. The 10 progeny of the sources of inocum and the 27 progeny of the inoculated hills were all grown in the me greenhouse in the following summer, when neither group showed y mosaic symptoms. If infection took place, it was masked in the cond generation. This was in contrast to parallel inoculations with e rugose type of mosaic, where symptoms appeared in both generations . 52).

Fifteen healthy plants representing six different tubers were inoculated ur times at approximately weekly intervals, with inoculum taken from mild mosaic vine and applied by the leaf-mutilation method. The first oculation was made when the plants were from 3 to 9 cm. in height, ebruary 1, 1922, and the last on February 23, in the Washington D. C.) greenhouse. On March 1 the first mild mosaic symptoms apeared on the young leaves in 2 plants and by March 21, 10 additional lants, or 80 per cent, showed mottling. The same number of vines ere mild mosaic on all leaves in the second generation. The character these symptoms was like those on the vines with a single inoculation ith mild mosaic made in December, previously described. Accordingly, peated inoculations produced a higher percentage of infected plants an a single inoculation. All uninoculated controls from the same bers as the inoculated plants remained healthy in both generations. t may be pointed out that the three unsuccessful inoculations and one ith incomplete current-season symptoms (on only one shoot) were made n plants among the 7 which were 5 cm. or less in height at the time f the first inoculation.

Leaf-mutilation inoculations with mild mosaic were performed again 1922, both in the open field and inside of insect cages, with currenteason symptoms in the cages (Pl. 2, A, 2). (For details see later section n "Inoculations performed in 1922.")

These results show that leaf-mutilation inoculation is sometimes, but ot necessarily, an effective means of infection with mild mosaic and ight explain the skepticism of certain workers in Holland regarding his method were it not that this skepticism is apparently not based on ny trial of this method, but rather on a needle-prick method (*4, p. 19*), hich the writers long ago discarded as useless (discussion on streak, . 53).

INSECT INOCULATIONS

It is thought that mild mosaic alone was involved with several expe ments previously reported (*45, p. 261–66; 40, p. 326–28; 41, p. 54–*) as giving transmission with aphids within Green Mountains, but furth experiments were made.

In 1921, six healthy hills of as many tuber units were caged, ea cage containing two of these hills separated by a hill having both mi mosaic and the spindling-tuber disease. Potato aphids, *Macrosiph solanifolii* Ashmead,[3] were introduced upon the diseased plants and fro each of these either dispersed or were transferred to the healthy h or hills in the same cage. Later they were sprayed with nicotine solu tion. Data are presented in Table II.

Two of the five inoculated hills became mosaic, with symptoms on in the progeny. The five control hills in the same tuber units but different cages were healthy and their progeny, 15 tuber units, we healthy. It is to be noted that complete mosaic infection occurred on in the hill (No. 1 of cage B–3) where there was the earliest dispersal aphids, where the aphids were not all killed by the first spray applicatio and where there was only one healthy hill to which to disperse.

In 1921, in another cage, aphids transmitted both mild mosaic an spindling tuber (Table XVI, inoculation No. 14).

TABLE II.—*Mild mosaic and spindling-tuber inoculations of caged Green Mount with aphids, in 1921*

Cage.	Diseased hill.		Healthy hills.					
	Number.	Aphids introduced.	Number.	Aphids transferred.	Date of spraying for aphids.	Progeny.		Spindling tuber.
						Total tuber-units.	Mosaic.	
							Per cent.	*Per cent.*
B–1	2	June 28.	1	July 9 and 13.	July 18.	4	0	[illegible]
		July 9.	3	do.	do.	4	25	[illegible]
B–2	2	June 28.	1	July 9 and 18.	July 23.	2	0	[illegible]
		July 9 and July 13.	3	do.	do.	4	0	[illegible]
B–3	2	June 24.	1	July 13 (dispersal by July 9).	July 18 and Aug. 22.	5	100	[illegible]
			3	Hill removed.				

Further data on aphids will be given in connection with interspecific transmission.

Negative current-season results have been reported from transferring flea beetles, *Epitrix cucumeris* Harris, in abnormally large numbers from mosaic to healthy plants (*40, p. 329*). The progeny of the healthy plants were all healthy, whereas 65 per cent of corresponding ones treated with aphids were mosaic.

In 1920, flea beetles again were introduced from mosaic plants int field insect cages in large numbers and allowed to feed upon health

[3] The authors wish to thank Dr. Edith M. Patch of the Maine Agricultural Experiment Station and Dr. A. C. Baker of the Bureau of Entomology, U. S. Dept. of Agriculture, for frequent identifications of aphids.

ants. They also fed upon mosaic and healthy plants in the same cage. some cages all plants were growing in the field soil, with roots and vines contact, and in others the healthy plants were potted with only the nes in contact with the diseased plants. Controls with no flea beetles esent were grown. In spite of special precautions, potato aphids ere introduced with the flea beetles into some cages. The exclusion aphids is a difficulty also experienced by others (*39, p. 134*). The ta have been presented in Table I. No current-season symptoms were anifested. The second generation had mosaic only in the progeny the hills inoculated by aphids.

In this experiment (Table I, Series 4) attempts were made to test the ossibility of transmission by larvae of flea beetles. A healthy Green ountain plant was caged and outside its cage a mosaic plant was grown rtly caged, and subjected under the small cage to severe infestation by a beetles. The infested part was badly damaged but no flea beetles erged at any time outside the large cage, whereas introduction of rge numbers of this species into other large cages was followed later in e season by the emerging of a second generation numerous enough to eletonize the laves. It seemed that the flea-beetle larvae feeding upon e mosaic plant did not travel far enough to reach the next hill. No fects were evident in either generation.

In 1919, experiments were performed with Colorado potato beetles, *ptinotarsa decemlineata* Say., as with the flea beetles, with similar gative results in both the first (*40, p. 329*) and the second generations. his beetle does not move from plant to plant as much as does the flea etle. Its feeding habits result in more complete destruction and less ounding of the tissues. Although larger, its individuals are less numerous the early part of the season when the plants are small. Altogether, would seem to be less liable to prove a carrier than the flea beetle.

LEAF-ROLLING MOSAIC

The symptoms of "crinkle" as described by Murphy (*29, p. 71–74*) em to be applicable in part to a leaf-rolling type of mosaic "approaching mewhat to the appearance of curly dwarf," and in part to "rugose osaic" as described later in this paper. The writers here use the term leaf-rolling mosaic" as designating a symptom complex that so far has een irreducible to simpler complexes, and that consists of slight dwarfing, iffused mottling, wrinkling, slight ruffling, and rolling of the upper aves (Pl. 2, B, 2, C, 1). It is different from mild mosaic in respect to e distinctness of the mottling, the presence of rolling, and the effects in mbination with the spindling-tuber disease, and is similar to it in fectiousness. The tuber symptoms are a general average reduction in ze. It is distinct from leaf roll.

Intervarietal inoculations of Green Mountains will be described later. eaf-mutilation inoculations of 10 hills within the variety in the open eld in 1922 gave no current-season symptoms, in contrast with rugose osaic. Inoculations of an apparent combination of leaf-rolling mosaic nd the spindling-tuber disease were made within the Green Mountain ariety in 1921 in an insect cage. Potato aphids from a "curly dwarf, aguely mottled" hill dispersed and were transferred to a healthy hill hose progeny were curly dwarf in two tuber units and spindling tuber n both these two and in the third tuber unit which was not curly dwarf. he progeny of the diseased hill which was the source of the inoculum,

and of the inoculated hill, are shown in Plate 3, A, B. It seems probable that the spindling-tuber disease (p. 55) was introduced into all three tubers of the inoculated hill, while leaf-rolling mosaic was introduced into only two, both diseases being manifested when in combination as mottled curly-dwarf (*47, Pl. 2; 32, Pl. 13*).

Intervarietal inoculations, described later, transmitted leaf-rolling mosaic alone to Green Mountains (Pl. 2, C 1).

RUGOSE MOSAIC

A type of mosaic much more infectious than mild mosaic, as will be shown later, is further differentiated by distinct dwarfing, more chlorosis and more diffused mottling, a more rugose type of wrinkling, and a tendency to show brittleness, spotting, streaking, leaf dropping, and premature death (Pl. 1; 3, C, 1; 4, A, 1), especially when in combination with the spindling-tuber disease. It is equivalent in part to the medium plus mosaic of the writers' previous publications (*40, p. 316*). The tuber symptoms are a marked reduction in size.

The writers believe that most of Murphy's crinkle (*29, p. 71–74*), is identical with the type here designated as "rugose mosaic" with some leaf-rolling mosaic symptoms included by Murphy. It is probable that the name "crinkle" is more descriptive of this disease in a large number of varieties, because of the mottling being generally masked, but the facts, first, that there is mottling, and, second, that the masking of mosaic is generally realized to be fairly common, make it seem unnecessary to abandon here the well-known term "mosaic." The symptoms of "crinkle" as given by Atanasoff (*4, p. 15–16*) include "a heavy mosaiclike variation in color," which can serve very well to describe the writers' "rugose mosaic." This type of mosaic in some varieties (*42*) and in some combinations (*14*) produces an extreme form known as "mosaic dwarf." "Mosaic dwarf," however, as suggested by Krantz and Bisby (*21, p. 7*), seems to the writers to contain more than one disease or symptom-complex. A current-season or primary symptom of crinkle is leaf dropping (*39, p. 139*), which is also a symptom of other degeneration diseases and combinations. Rugose mosaic is more infectious, or at least more generally conspicuous, than mild mosaic in varieties in the Cobbler, Rural, and Rose groups (*48*) and perhaps others (*45, p. 249*), and also is more common in southern regions than in northern.

It is thought probable that the striking current-season symptoms reported for mosaic leaf-mutilation inoculations in the open field in 191- (*40, p. 320–23*) were involved with the rugose type of mosaic. Intervarietal transmission to Green Mountains was effected in 1920 and 192- (p. 66).

Leaf-mutilation inoculations with rugose mosaic were made in the Orono, Me., greenhouse in the winter of 1921–22, in eight hills from four tuber units. The sources of inoculum were three hills that were progeny of field-grown plants with streaking but, in one case, with no mottling, and showed dwarfing, mottling, wrinkling, spotting, burning, and leaf dropping. Of the inoculated hills, two showed leaf dropping in 17 days, five in -- days, and one in 42 days, and one showed mosaic in the uppermost leaves. Most of the progeny (17 of 18) of the inoculated hills, when grown in the same greenhouse in the following summer, were mosaic, completing the contrast to parallel inoculations with mild mosaic where no symptoms ap-

ared in the inoculated hills and where even the progeny of diseased lls showed no symptoms during the summer (p. 49). The eight con-ols and 13 of their progeny grown in the greenhouse were healthy.

A number of leaf-mutilation inoculations with rugose mosaic were per-rmed again in 1922, usually with current-season symptoms in the open ld as well as in the cages (p. 76).

Intervarietal aphid transmission of rugose mosaic to Green Mountains ill be described later (Pl. 4, A).

STREAK

Most of the streaking seen by the writers has been associated with gose mosaic (Pl. 4, B, C), but in at least one case the latter was absent that streak (*5, p. 50; 33; 29, p. 76–82; 4*) may be considered as a distinct mptom complex. The current-season symptoms appear in a certain der after leaf-mutilation inoculation, as streaking and spotting, burning, ittleness, leaf dropping, and premature death, with no mottling except r chlorotic spots a few hours previously in the places where streaking nd spotting occur, and no wrinkling (Pl. 5, A, C; 11, C; 12,B).

Symptoms following tuber perpetuation are extreme dwarfing, wrink-ng, curling, rugosity, brittleness, leaf dropping, and premature death Pl. 6, A, 2, B, 1). In this connection a study of other works (*29, p. 80;* , *p. 16*) is interesting. The tuber symptoms are extreme reduction in ze, with some darkening, near the eyes, that resembles small initial fection spots of late blight; *Phytopthora infestans* de By. Cracking r splitting of the tubers has been observed for streak by Atanasoff *4, p. 9*), as also for curly dwarf and leaf roll by Orton (*32, Pl. 13*), for ellow dwarf by Barrus and Chupp (7), and for unmottled curly dwarf y the writers (p. 60).

Intervarietal transmission was effected in 1921 (p. 69; Pl. 5, A, C) as previously reported (*42*). These results were confirmed with the same methods of inoculation within the Green Mountain variety in 1922, described later. In regard to the 1921 report, Atanasoff (*4, p. 18–19*) writes:

b. Plant juice. Schulz and Folsom claim to have been able to infect potato plants with stipple-streak by means of juice from an infected plant. "In 1921," they write, "juice from a streak plant applied to 20 mutilated Green Mountain and Irish Cobbler plants caused infection in 19, with typical symptoms appearing in some in 12 days.

He then describes inoculations made in Holland "in order to verify this statement" and concludes it to be "highly improbable that the plants infected by Schulz and Folsom have become diseased as result of their infection." Some discussion seems necessary here.

The above quotation (*42*) should have been completed as follows:

Sixty control hills in the same tuber units, from quartered tubers, remained healthy.

The following of inoculation by the disease in 95 per cent of the 20 inoculated hills, in two varieties, with the absence of both inoculation and disease in the 60 control hills, is a contrast more convincing, at least to the writers, than reports of successful grafting with all figures omitted (*4, p. 20*), though the writers by no means doubt the latter report. It is a contrast less impressive than with 100 per cent, or with 95 per cent in 2,000 inoculated hills, but is nevertheless significant.

Verification experiments are misleading when different methods a used. The writers' method was that previously reported by the (*40, p. 320–26*) and included severe bruising of the leaves. The meth described by Atanasoff (*4, p. 19*) introduced a drop of juice into split stem, resembling the capillary-tube and split-stem methods also us by the writers (p. 74, 83) in 1921 and discarded because of ineffectivene

Even had Atanasoff's method been similar to the writers' and giv negative results, it is well to make allowance for climatic factors. Neg tive results with aphid inoculations of leaf roll by Murphy (*29, p. 52*) c not prevent later proof, and probably would not have been weighed him more heavily than his negative results with mosaic and inse (*29, p. 62*) had he not been emphasizing the soil-transmission theo advanced by the Dutch workers but later abandoned by them.

After tuber perpetuation, the progeny of the plants inoculated 1921 were used in inoculations described later in the section on "Inoc lations performed in 1922," and the same positive results were obtain with spotting of the white corollas in addition.

LEAF ROLL AND NET NECROSIS

Leaf roll, as previously described by the writers (*41, 15*), is charact ized chiefly by dwarfing, chlorosis, rolling, uprightness, and rigidi burning also is common (Pl. 6, C, 2). Phloëm necrosis is a microsco symptom of great value for positive identification (*39, p. 132*). Leaf r is less easily transmitted than any other degeneration disease conside in this paper (*29, p. 65*). The size of the tubers is reduced. Streakin (from phloëm necrosis) in the tubers (net necrosis) previously reporte as a symptom by the writers (*41, p. 60–74*) and by Gilbert (*17*) and Kasa (*20, p. 52, 69*) has been noted again as a symptom in plants grown in 192 and 1922. This tuber symptom of leaf roll was reported (*41, p. 68*) as being sometimes induced by varietal and other factors, but did not necessitate (*41, p. 73*) long storage as suggested by Quanjer (*39, p. 132*), and was not a constant symptom as he understood it. The observations made in 1921 on net necrosis are given in a later section (p. 64).

Inoculations within the Green Mountain variety have been reported as giving positive results with stalk grafts and aphids (*41, p. 52, 54–55, 57–59*). Intervarietal inoculations like these, and also unsuccessful attempts to transmit leaf roll by leaf-mutilation inoculation, will be described later (p. 63).

In the winter of 1921 and 1922, an experiment on the effect of healthy potato plants grown in contact with tuber and vines diseased with leaf roll (with insects excluded) was conducted at Washington, D. C. This test was conducted in the same manner and at the same time as the experiment on the effect of growing healthy potato plants in contact with mosaic plants. In this experiment nine healthy half tubers were planted in contact but not grafted with leaf-roll half tubers, while each of the remaining six healthy half tubers was planted 6 inches apart from the leaf-roll half tuber in the same 10-inch pot. Three observations on the vines during the course of the experiment revealed that all vines from leaf-roll tubers showed leaf roll, while the vines from healthy tubers remained free from leaf roll. Second-generation plants from the healthy tubers likewise were free from leaf roll, as microscopic as well as macroscopic examinations disclosed.

SPINDLING-TUBER DISEASE

The spindling-tuber disease (*43, 44*) is characterized always by spindliness and uprightness, and often by a darker green color and slight rugosity. The tubers are abnormally spindling, spindle shaped, cylindrical, and supplied with conspicuous eyes, these symptoms varying somewhat with the variety (Pl. 7, A, 2, 3, B, 1, C, 1; 8, A, 2, B, 2, 3, C, 1, 2; 9, A, B, 1, 2; 10, B, 2, C, in center). A lighter red color obtains in spindling-tuber Red Bliss Triumph tubers than in the healthy tubers of this variety. This disease is readily distinguished from the mosaic diseases by the absence of mottling, and from leaf roll and streak. It is about as easily transmitted as mild mosaic and leaf-rolling mosaic, and therefore less easily than rugose mosaic and streak, and more easily than leaf roll. It reduces the amount of tuber progeny, but because of the difference in shape it may not be readily apparent that the size is reduced below that of uninfected plants.

The spindling-tuber disease of the potato has been recognized for many years by growers and others by various names, such as "running out," "running long," "off shape," "poor shape," "reversion" and "senility." Observations made by the writers on this potato trouble from 1917 to 1921, in connection with investigations on mosaic and leaf roll, indicated its infectious nature. If strains free from this malady were planted near stock with a high percentage of "run out" tubers, a considerable percentage of such tubers resulted in a few years. Elimination of "run out" tubers by selecting only the good, normal-shaped tubers at the time of planting did not produce stock free from such progeny. In fact, in some lots the percentage of spindling tubers increased during this period so that a few lots produced practically 100 per cent spindling tubers. Similar selection of well-shaped tubers by growers from stock with a high percentage of spindling tubers, likewise has failed to produce stock free from this malady. A part of a strain planted under soil, temperature, moisture, fertilizer, and other environmental conditions similar to those of another part, with the exception that it was grown nearer spindling-tuber lots than the other, the next year contained a higher percentage of spindling-tubers. Furthermore, it was noted that normal and spindling-tuber progeny frequently developed in the same hill lot and even in the same tuber unit, just as obtains with mosaic and leaf roll. This was noted by Stewart (*46, Pl. 10*).

Accordingly, during the season of 1921, additional selections for studying the nature of this malady were made. In a field of Green Mountains having less than 1 per cent of spindling-tuber, two lots of healthy hills were selected, one grown next and the other not next spindling-tuber hills; similar selections were made in two fields of Irish Cobbler having 5 and 15 per cent spindling-tuber hills, respectively. Further selections from Green Mountain and Bliss Triumph lots in experimental plots were made. In 1922, these different lots were planted and the percentage of spindling tubers noted as indicated in Table III.

Table III shows that the percentage of spindling-tuber decreases as the distance from diseased hills increases, and that a higher percentage of infection of healthy hills obtains as the percentage of spindling-tuber increases. These data also suggest that spindling-tuber may be transmitted fully as readily as mild mosaic in conditions apparently as favorable regarding the source of infection.

In field 34, Table XXVIII, the spread from diseased rows was su that samples from the first adjacent healthy row gave progeny w 60 per cent of the hills diseased, while six samples from more dista rows gave progeny with only 10 per cent diseased.

TABLE III.—*Effect of proximity of healthy hills to hills with the spindling-tuber dise*

Field.	Lot.	Variety.	1921: Spindling tuber in field.	1921: Number of healthy hills and location: Adjacent.	1921: Number of healthy hills and location: Not adjacent.	1922 progeny: Number of tuber units.	1922 progeny: Spindling tuber.	1922 progeny: Mos
			Per cent.				*Per cent.*	*Per c*
A	1	Green Mountain	1	10	....	47	30	
	2	do	1	....	10	40	0	
B	1	Irish Cobbler	15	10	....	42	90	....
	2	do	15	....	10	38	71	....
C	1	do	5	10	....	47	85	....
	2	do	5	....	10	51	63	....
D	([b])	Bliss Triumph	[c]100	48	....	....	60	

[a] Bulk stock contained 10 per cent mosaic in 1921 and 17 per cent in 1922.
[b] No spindling tuber in 1920.
[c] Adjacent plot. Also 100 per cent mosaic.

Measurements were made of a number of lots of tubers grown in 192 using a slide caliper of special construction duplicating one devised b F. A. Krantz, of the Minnesota Agricultural Experiment Station. Th longest dimension parallel to the structural axis of the tuber was con sidered the length, while the greatest and least dimensions perpendicul to the axis were called, respectively, the width and depth. Each l consisted of tubers taken at random from the top of a barrelful that ha been picked up by chance in the field. When each tuber was measure a record was also made of the presence or absence of spindling-tub symptoms. The results of measuring several Green Mountain lots a summarized in Tables IV, V, and VI. The first three lots in each tab consist of diseased tubers, but they were selected in three successi years, respectively. Their similarity in the correlation tables (Table IV and in the ratios calculated for L/W (length/width) and W/D (widt depth) in Table V show how persistent the dimensional characteristics a when once the disease has entered the tubers and reduced their widt their similarity being more significant for W/D than for L/W. Th fourth and last lots, from two different strains, are both health and are much more alike than diseased and healthy parts of the sam strain or even of the same 1921 plot, especially in W/D. The fifth an sixth lots, grown in the same 1921 plot, are similar although grown o two types of soil, having about 40 per cent of the tubers diseased, an are midway between healthy and diseased lots in dimensional char acteristics. It is clear, therefore, that there is a high correlation betwee mechanically determined dimensions and diagnosis of the spindlin tuber disease from tuber symptoms, even when this diagnosis was mad one or two years previously. Mosaic as well as soil had no appare

ent here, the third and fourth lots both having had mosaic throughout for several years.

With spread in the field and perpetuation in the tubers demonstrated, infection experiments are of interest. As described in connection with mild mosaic (p. 50 and Table II) and with leaf-rolling mosaic (p. 51), aphids transmitted the spindling-tuber disease in insect cages in 1921 to three hills. The controls, in the same tuber units but in different cages, were healthy in both generations.

TABLE IV.—*Correlation of width with length and depth in Green Mountains grown in 1921*

Lot No.	Width.	Length (centimeters).											Depth (centimeters).				
		6	7	8	9	10	11	12	13	14	15	16	4	5	6	7	8
CT-8	4		1		1								2				
	5	1	3	10	4	8	1		1				7	21			
	6		1	7	10	15	8	10		1				33	19		
	7					3	1	4	4	3	1			1	14	1	
	8						1	1								2	
	9																
	10																
CT-9	4		3	1	1								5				
	5	1	1	6	11	10	3	5					8	29			
	6			1	7	8	11	7	5	2				32	9		
	7						6	1	4	5		1		3	11	3	
	8																
	9																
	10																
Bs. Spindling tuber	4		2										2				
	5		7	19	24	9							14	45			
	6		1	12	16	19	17	3	2				1	57	12		
	7				2	5	2	3	2	1			1	4	10		
	8				1	1					1			1	1	1	
	9																
	10																
B. *Healthy*	4																
	5																
	6	1	12	3	2	2								19	1		
	7	2	6	13	6	7	4	1						24	15		
	8		2	5	10	6	5							5	21	2	
	9				1	6	3	3	1					1	8	5	
	10																
-11. Caribou ...	4																
	5			1	6	7	4	1					5	14			
	6		2	3	3	9	1	2	3				1	19	3		
	7		3	4	10	4	6	2	2					15	15	1	
	8		1	3	1	2	7	4	3					4	12	5	
	9			1	2		2			1				1	3	2	
	10																
-13. Washburn ...	4				1								1				
	5			5	4	2	2	1					3	11			
	6		2	3	6	6	8	4	2	1				25	7		
	7		3	2	10	9	5	3						16	15	1	
	8		1		2	5	2	5						2	9	4	
	9				1		2	2							4	1	
	10									1							1
S-54	4																
	5																
	6		2	1	2								2	3			
	7		2	6	9	6	2							12	13		
	8			4	9	8	8	8	2	1				7	28	5	
	9					2	3	2	1	1	1			1	3	6	
	10																

Figures show numbers of tubers with dimensions indicated at left and at top.

TABLE V.—*Dimensions of tubers of Green Mountains grown in 1921*

1921 plot No.	Strain.	Description of lot measured.	Number of tubers.	Diseased with spindling tuber.	Ratio of length/width (L/W).[1]	Ratio of width/depth (W/D)
				Per cent.		
CT-28	LK, secured in 1916 as mosaic-free.	Spindling tubers selected in winter of 1919-20.	100	98	1.722±.017	1.121±[illegible]
CT-29	do	Spindling tubers selected in winter of 1920-21.	100	99	1.863±.017	1.12[illegible]
Y-6B	LK, selected in 1916 as mosaic.	Spindling tubers selected in winter of 1921-22.	149	100	1.658±.011	1.144±[illegible]
Y-6B	do	Healthy tubers selected in winter of 1921-22.	101	0	1.213±.012	1.318±[illegible]
CT-13	LK, selected in 1916 as mosaic-free.	Grown on Caribou loam in 1921.	100	40	1.540±.023	1.24[illegible]
CT-13	do	Grown on Washburn loam in 1921.	100	37	1.541±.021	1.222±[illegible]
MSS-S4	B		80	0	1.302±.013	1.3[illegible]

[1] Calculations were performed by the Biology Department, Maine Agricultural Experiment Station.

TABLE VI.—*Comparison of plots of Table V, giving difference between means and probable error of difference;*[1] *also ratio between difference and its probable error*

LENGTH/WIDTH

	CT-29.	Y-6B. Spindling-tuber.	Y-6B. Healthy.	MSS-S4.	CT-13 Washburn loam.
CT-28	.141±.024	.064±.020	.509±.021	.420±.021	
Difference/P. E.	(6:1)	(3:1)	(24:1)	(21:1)	
CT-29		.205±.020	.650±.021	.561±.021	
Difference/P. E.		(10:1)	(31:1)	(27:1)	
Y-6B. Spindling tuber			.445±.016	.356±.017	
Difference/P. E.			(28:1)	(21:1)	
Y-6B. Healthy				.089±.018	
Difference/P. E.				(5:1)	
CT-13. Caribou loam					.001±[illegible]
Difference/P. E.					(1:3[illegible]

WIDTH/DEPTH

	CT-29.	Y-6B. Spindling-tuber.	Y-6B. Healthy.	MSS-S4.	CT-13 Washburn loam.
CT-28	.001±.011	.023±.010	.197±.011	.206±.012	
Difference/P. E.	(1:11)	(2:1)	(18:1)	(17:1)	
CT-29		.022±.011	.196±.011	.205+.013	
Difference/P. E.		(2:1)	(18:1)	(16:1)	
Y-6B. Spindling tuber			.174±.011	.183±.012	
Difference/P. E.			(16:1)	(15:1)	
Y-6B. Healthy				.009±.013	
Difference/P. E.				(1:1.5)	
CT-13. Caribou loam					.020±[illegible]
Difference/P. E.					(1.3[illegible]

[1] Calculated as the square root of the sums of the squares of the probable errors of the means.

Further infection experiments including inoculation with leaf mutilation, tuber and stem grafts, and aphids, were initiated on plants in the greenhouse and in cages in the field, as well as under open field conditions. The procedure in these infection tests was similar to those observed with such operations in connection with the writers' studies on mosaic and leaf roll of potato. The results of these experiments are presented in Table VII.

Inoculation series.	Inoculation.				Inoculated hills.		Controls.[a]		Remarks.
	Variety.	Type.	Location.	Date.	Number treated.	Infected.	Number.	Infected.	
						Percent.		Percent.	
1	Green Mountain	Tuber graft	Greenhouse, Washington, D. C.	Nov. 21, 1921	10	90	10	0	Mosaic on two plants.
2	do	do	do	Dec. 22, 1921	7	100	7	0	Mosaic on one plant.
3	do	do	Presque Isle, Me	May, 1922	18	[b]83	20	0	Mosaic on one-third of inoculated plants, both infected and not infected with spindling tuber.
4	do	Vine graft	Presque Isle, Me. (in cages).	June, 1922	3	33	3	0	
5	Irish Cobbler and Green Mountain.	Leaf mutilation	do	July, 1922	14	57	14	0	
6	Green Mountain	do	Presque Isle, Me., in open field.	do	20	30	60	5	
7	do	Aphids	Presque Isle, Me., in cages.	do	6	33	6	0	

[a] Controls included half tuber seed piece from same tuber as grafted half tuber.

[b] Shown in Plates 8, C, and 9, A.

1-108—23——2

The data in Table VII indicate that infection with spindling tuber was obtained with tuber and vine grafts, leaf mutilation, and aphids. In inoculation Series 1 and 2 the reaction of the second-generation progeny is represented, which in part accounts for a higher percentage of successful inoculations than in the remaining series. No doubt the second-generation progeny in Series 5 to 7 will show a higher percentage of infection than the first generation, since with spindling tuber as with mosaic and leafroll, initial infections contracted late in the development of the plants in the first generation will not produce visible macroscopic symptoms in the same generation. Additional evidence on infection with spindling tuber by aphids is disclosed in Table XVI (inoculation No. 5, 8, 13, and 14) and by means of leaf mutilation in Table XVIII.

UNMOTTLED CURLY DWARF

Curly dwarf, described by Orton (*32, p. 37–40*), seems to be in part at least, a combination of two or more degeneration diseases, as has been suggested by Murphy (*29, p. 69*) and by Quanjer (*39, p. 127–128*). It will be considered as such in the following section of this paper. However, a symptom complex here designated as unmottled curly dwarf in Green Mountains, has remained too true to type for three years to be considered yet as a combination of diseases, although it may eventually be demonstrated to be such. It consists of pronounced dwarfing, spindliness, dark green color of the foliage early in the season, wrinkling, rugosity, slight ruffling, curling, some rolling, uprightness, brittleness, burning, somewhat premature death, and spindling, gnarled, and cracked tubers (Pl. 11, A, B, 2, 3, 5; 12, A, 1). It may be the result of leafrolling mosaic and the spindling-tuber disease together with the mottling of leaf-rolling mosaic masked by the spindling-tuber disease. If so, the combination known as "mottled curly dwarf" would appear to be the same with the addition of mild mosaic, an assumpton that is hard to accept in view of the fact that the tubers are not so small and cracked in "mottled curly dwarf" as in "unmottled curly dwarf."

Leaf-mutilation inoculations were made in the open field in 19[illegible]. Inoculum was secured from an unmottled curly-dwarf hill and introduced into the second and third hills of each of four 4-hill tuber units. The symptoms appeared first in 1921, and again in 1922 in the open field and in the winter of 1921–22 in the greenhouse, always as unmottled curly dwarf. Intervarietal transmission with aphids will be described later.

Leaf-mutilation inoculations were made in the Orono greenhouse in the winter of 1921–22 in six hills from three tuber units. The two progeny of one of the inoculated hills showed the same symptoms as the 19[illegible] field symptoms resulting from the 1920 inoculations, even to the gnarling and cracking of the seven spindling tubers. However, the percentage of infection was much lower than for rugose mosaic in a parallel series of inoculations (p. 52).

COMPARISON OF DISTINCT DISEASES

The several symptom complexes, presumably different diseases caused by distinct though somewhat similar viruses, that have been previously considered in this paper may be compared in Table VIII. There a symptom is to be considered as absent if not noted for a disease. The

acterization given is typical of Green Mountains in northeastern ne and does not include variations due to environmental factors, ee of maturity, and current-season inoculation. It may be pointed here that Quanjer (*39, p. 140*) suggests the possibility of viruses pting themselves to new varieties, and that this in turn suggests the stion of change of a virus in the same variety leading to new symptom plexes somewhat related to the old, as are streak and rugose mosaic ent-season symptoms, mild mosaic and leaf-rolling mosaic, curly rf (combination of leaf-rolling mosaic and spindling tuber) and ottled curly dwarf. Also, a varietal modification of a virus if occur- might be permanent even when the virus is returned to the variety inally affected. It may also be suggested that different viruses or sal agents may account for the differences in symptoms.

LE VIII.—*Symptoms and transmission of degeneration diseases of potatoes in the Green Mountain variety*

e of disease.	Size.	Stem texture.	Color.	Leaf texture.	Leaf form.
mosaic	Slight dwarfing		Distinct mottling.	Tenderness	Wrinkling, ruffling.
-rolling mosaic.	do		Indistinct mottling.	do	Wrinkling, ruffling, rolling.
ose mosaic	Distinct dwarfing.	Brittleness	Mottling and slight chlorosis.	Slight stiffness	Wrinkling, rugosity.
k.	Severe dwarfing after tuber perpetuation.	do		Tenderness after tuber perpetuation.	Wrinkling, curling, and rugosity after tuber perpetuation.
roll	Distinct dwarfing.	Rigidity	Chlorosis	Stiff and leathery.	Rolling.
dling-tuber sease.	Spindling		Dark green early in season.	Slight stiffness	Slight rugosity early in season.
ottled curly warf.	Severe dwarfing	Brittleness	do	do	Wrinkling, ruffling, rolling, curling, rugosity.

ame of disease.	Necrosis.	Tuber symptoms.	Transmission demonstrated.[1]	Incubation period.
mosaic			Grafts, aphids, and leaf mutilation.	Usually over 25 days.
-rolling mosaic			Aphids	Nearly like mild mosaic.
ose mosaic	Varying; more streaking from current-season inoculations.		Aphids and leaf mutilation.	About 14 days.
eak	Streaking, spotting, leaf dropping, premature death.	Browning near eyes.	Leaf mutilation	About 12 days.
f roll	Burning	Streaking (net necrosis).	Grafts and aphids; leaf mutilation unsuccessful.	Usually over 25 days.
ndling-tuber disease.		Spindling	Grafts, aphids, and leaf mutilation.	Do.
mottled curly warf.	Burning, stem streaking.	Spindling, cracked	Aphids and leaf mutilation.	Do.

[1] Including intervarietal transmission into Green Mountains, as described in this paper.

COMBINATIONS OF DISEASES

When a certain symptom complex contains the symptoms of two or ore of the several distinct diseases described in the preceding pages, d is associated with them, diagnostic evidence is therefore present, dicating that the former is a combination of the latter. Analytical

evidence of such combinations has been obtained, consisting of t... results of inoculations in which one or more of the combined disea... are transmitted separately to new hosts of the same variety. Su... evidence easily discloses a more infectious disease in the combinati... but a less infectious disease will seldom be separated analytically fr... others not more infectious. Synthetic evidence, obtained by inocula... ing in such a way that new diseases are introduced into diseased pla... or so that diseases are combined in healthy plants, is difficult to sec... except where transmitting insects are controlled, especially when d... eases are involved with a long incubation period and a consequent infr... quency of current-season symptoms.

There are many theoretically possible combinations of the several d... eases that have been discussed. The number of actual combinatio... observed by the writers has been reduced from the theoretical numb... by several factors. In northeastern Maine, leaf roll is rare in nat... stocks and often decreases or disappears in infected stocks. Many co... binations quickly eliminate themselves by their excessive reduction... the yield and by causing premature death and thus reducing the chan... for insect transmission. Varietal susceptibility also seems to be of in... ence. Furthermore, without synthetic evidence it may be assumed th... the results of some combinations may be a masking of some of the sym... toms of the separate diseases entering the combination. It is possi... for the writers at present to show only the general significance of t... principle that combinations of degeneration diseases may exist.

The writers, even with the limitations just previously set forth, ha... seen symptom complexes that evidently were combinations of diseas... Double combinations are more easily diagnosed than triple combin... tions. Several combinations are given in Table IX as having be... observed by the writers. Combinations are given by Murphy (*29, p.* ...), Quanjer (*39, p. 128*), and Gilbert (*17*).

TABLE IX.—*Combinations of degeneration diseases thought to have been obser... Green Mountain potatoes*

Name of combination as formerly described.	Combined diseases.						
	Mild mosaic.	Leaf-rolling mosaic.	Rugose mosaic.	Streak.	Leaf roll.	Spindling tuber.	[illegible]
	X			[a] X			
	X			[a] X		X	
	X				X		
Medium mosaic. (In part.)	X					X	
Mosaic dwarf, bad mosaic. (In part.)		X	X			X	
		X			X		
Mottled curly dwarf		X				X	
Mosaic dwarf; bad mosaic. (In part.)			X	X			
Medium plus mosaic. (In part.)			X			X	
				[a] X		X	
					X	X	

[a] Probably first season symptoms of rugose mosaic.

s reported previously (*41, p. 54–55*), in 1919 aphids were transferred n a plant with both mild mosaic and leaf roll to three healthy hills n insect cage, and a higher percentage of the progeny were leaf roll per cent) than were mosaic (57 per cent). As is shown in Table II, ids from hills both mild mosaic and spindling-tuber, with contact h those hills, resulted in mosaic infection of two hills, spindling tuber ction of two hills, and in no infection of a fifth hill. As described page 51, aphids from a "mottled curly-dwarf" (or spindling tuber + -rolling mosaic) hill infected a hill in an insect cage partly with y dwarf and partly with the spindling-tuber disease alone (Pl. 3, 1, 2).

CLUSIONS REGARDING TRANSMISSION AND DIAGNOSIS IN THE GREEN MOUNTAIN VARIETY

Vithin one variety in a given time and place, it has been possible to inguish diagnostically several degeneration diseases of potatoes, urring both singly and in combinations. These several degeneration ases can be studied to advantage by means of inoculations with fts, aphids, and the leaf-mutilation method. In this way further inctions can be made between the more similar diseases such as the es of mosaic, and combinations of diseases can be divided. The ne methods have been used in Minnesota in this variety in "mosaic-arf" inoculation by grafting, leaf mutilation, root contact, and expo-e to insect dispersal from diseased plants, with similar results, positive ept with root contact (*21, p. 13–22*).

ANSMISSION AND DIAGNOSIS WITHIN VARIETIES OTHER THAN THE GREEN MOUNTAIN

It is thought that the several diseases described in the preceding pages Green Mountains are present also in other varieties. Assuming that re may be varietal modification of symptoms, as will be shown later this paper to be possible, intervarietal inoculation is necessary for clusive proof that a symptom complex in one variety is caused by same virus as a symptom complex in another variety. However, s thought that leafroll and the spindling-tuber disease can often be rectly diagnosed outside of Green Mountains without intervarietal culations.

n 1920, as is described partly in a previous paper (*41, p. 53*), leaf-roll culations were made on Irish Cobblers inside of insect cages by means grafting, leaf mutilation, aphids, and contact. The progeny were erved in 1921, with the data given in Table X. It is clear that fting and aphids were the only effective means employed, and that ids were not as effective as with mosaic in the same season (Table Corresponding leaf-mutilation inoculations in the open field in two hills of each of 12 four-hill tuber units, gave negative results in h generations. Kasai (*20, p. 66*) describes reduction of leaf-roll tamination by the use of field insect cages in Japan.

Leaf-mutilation inoculations were made in the Orono greenhouse ing the winter of 1921–22 in Irish Cobblers, with rugose mosaic, h leaf roll, and with a combination of the two. The four hills inocu-d with rugose mosaic showed leaf dropping in from 25 to 50 days. ir 12 progeny were mosaic, with leaf dropping. The four controls

in the same two tuber units were healthy, as were their 4 progeny gro in the greenhouse. Two hills had the combination of leaf roll and rug mosaic. One of these lived longer than the three hills with rug mosaic alone. The other was used as a source of inoculum for le mutilation inoculation of two hills which showed leaf dropping in and 50 days, respectively, but whose 8 progeny were healthy. Inocu tion with leaf roll alone in four hills of two tuber units gave nega results which persisted in the 14 progeny. The designation of rug mosaic here in Irish Cobblers is based on the results of parallel in varietal inoculations to Green Mountains.

TABLE X.—*Leaf-roll inoculations of caged Irish Cobblers in 1920*

Inoculation.			Progeny.	
Series.	Method.	Hills.	Tuber units.	Le r
				Per
1	Grafting stalks	6	29	
2	None, in cages of Series 1	3	9	
3	Leaf mutilation	4	24	
4	Aphids and full contact	6	39	
5	Aphids	9	51	
6	Full contact	6	23	
7	None, controls to Series 3, 4, and 6	9	22	

Inasmuch as hill selections in 1919 gave rise to leaf-roll progeny 1920 (when made next to leaf-roll hills) with a tendency to show m leaf roll and net necrosis with greater tuber weight (*41, p. 71*), sim hill selections were made in 1920. In Green Mountains, only 7 per ce of 183 progeny were leaf roll and 2 per cent net necrosis. In New Wh Hebrons, 28 per cent of the progeny in 1921 were leaf roll and 22 per ce were net necrosis. The relation to tuber weight is shown in Table X There was again an increase of each disease with an increase in tu weight.

TABLE XI.—*Correlation in New White Hebrons in 1921, between tuber weight, necrosis, and leaf-roll infection, at the time of planting* [1]

Tuber weight.	Number of tubers.	Net necrosis in tubers.	Leaf roll in tubers.
Ounces.		*Per cent.*	*Per cent.*
1	8	0	0
1 to 2	19	5	11
1 to 3	29	10	17
1 to 4	36	14	22
1 to 5	42	14	21
1 to 6	47	15	21
1 to 7	52	19	25
1 to 8	54	22	28

[1] Leaf-roll infection in tubers was ascertained from the appearance of their plant progeny in the part of the season.

TERVARIETAL TRANSMISSION AND VARIETAL MODIFICATION OF SYMPTOMS

Observations by the writers, made largely of plants grown or furshed by the Office of Horticultural and Pomological Investigations, nited States Department of Agriculture, have disclosed a great varian in apparently diseased plants in the many commercial and seedling rieties available. Many of the observations were made on an unrayed plot, maintained for the study of resistance to late blight, *ytophthora infestans* deBy., where mottling was not masked as much in frequently sprayed fields. Here, both in 1920 and in 1921, there ere such differences between the lots and between the hills of a given t, as well as between the symptoms observed on one date and another the same hills, that it seemed probable that there existed varietal sceptibility and varietal modification of symptoms. The question of e existence of such modification has been considered in experiments volved with natural uncontrolled field infection, with inoculations in e field, and with inoculations in the greenhouse.

GENERAL OBSERVATIONS IN THE FIELD

In 1919, small lots of different varieties were grown in rows alternatg with rows of mild mosaic Green Mountains. As the result of inction in 1918, all the 6 Triumph lots and 12 of the 14 Green Mountain ts thus planted were mosaic in over 19 per cent of the hills and were scarded. The other 2 Green Mountain lots and 1 lot each of three her varieties in the same group (*48*)—namely, Carman No. 1, Gold oin, and Norcross—contained no mosaic in 1919, but were sufficiently fected, presumably by insects from the alternating mosaic rows, to ave 48 per cent in the Gold Coin lot in 1920, and from 70 to 87 per cent the other lots. Twenty-one lots representing the Cobbler, Early ichigan, Rose, Early Ohio, Burbank, and Rural groups were grown in e same plot in similar alternation with mosaic Green Mountain rows. en of these, consisting of some of those from the Rural group, were scarded in 1920 for lack of room, when they showed no mosaic. The

est were grown between Bliss Triumph mosaic rows in 1920, and by 921, after two years of alternate-row proximity to mosaic plants, showed om none to 12 per cent mosaic. Either the Green Mountain and riumph groups were much more susceptible to mosaic, or they dislayed different symptoms from the other groups mentioned.

INTERVARIETAL INOCULATIONS IN THE FIELD

Results previously reported consist of the transmission of mosaic probably the rugose type) by leaf mutilation with current-season ymptoms (1919) from Bliss Triumph to Green Mountain, from Irish obbler to Green Mountain and to Bliss Triumph, and from Green Mountain to Bliss Triumph and to Irish Cobbler (*40, p. 324–26*). The rogeny of the inoculated hills were all "mosaic or mosaic dwarf" in 920—that is, infected with mild mosaic or rugose mosaic and cominations. As indicated elsewhere, the presence of disease in the second eason, following inoculation in the open field with insects uncontrolled, ften is not significant because of the controls having also contracted the isease from the neighboring inoculated hills. That was the case here, howing that sometimes observations on the first generation in an experiment, including the controls, are more valuable than those on the econd generation.

INOCULATIONS PERFORMED IN 1920

In 1920, leaf-mutilation inoculations were performed without any effects appearing before digging time, but some effects from the inoculations were apparent in 1921 in the second generation. The tubers were split in two and planted as two-hill tuber units. In 69 of the 90 series the juice was obtained from mosaic Green Mountains while the inoculated plants were mostly of different varieties in the Rural, Cobbler, and other groups, a few being Green Mountain controls. Progeny of these inoculated plants were diseased, with mosaic or curly dwarf, in 24 of the tuber units, or in about 6 per cent, and progeny of the controls in 7 of 509, or in about 1 per cent. This difference is not very significant, especially since the diseased units were not grouped in correlation with any condition of inoculation. In 21 of the 90 inoculation series the inoculated plants were Green Mountains of a certain strain while the juice or inoculum was obtained from other varieties except for a few Green Mountain controls. Five of these undoubtedly were successful in producing infection, and all are considered in detail in Table XII. Here it must be remembered that the terminology was more general regarding diseases than at present. The controls were hills in the same tuber units as the inoculated hills.

It is noteworthy that the stocks which served as the sources of inoculum in Series 5, 14, and 17 apparently recovered from mosaic in 1921. This apparent recovery was noted for other stocks, both by the writers in strains all mild mosaic for several years previously and by seed-certification officials over several States, and is to be attributed to seasonal modification or masking of symptoms. It will be discussed more fully later. It is probable that mild mosaic was not apparent even when the virus was present.

Inoculations in Series 5 and 8 were successful in inducing "mosaic" (probably not of the mild type) with symptoms in the progeny of slight dwarfing, slight wrinkling, slight burning, and mottling or chlorosis. Inoculation Series 2 and 16 would be considered successful also if the controls were healthy. Possibly the controls were infected by insects from the adjacent inoculated plants. Inoculation Series 3 and 4 were partly successful, being performed under control (insect-cage) conditions as a duplicate of Series 2. Inoculations in Series 7, 19, and 66 were successful in inducing "curly dwarf," with symptoms consisting of marked dwarfing, ruffling, curling, brittleness, stem streaking, and burning (Pl. 11, A, B, 2, 3, 5; 12, A, B). Disease appearing in 1921 as a mosaic was thus induced in Green Mountains by inoculation with juice from mosaic and curly-dwarf plants of the Rural type, and curly dwarf was induced with juice from dwarfed and wrinkled Netted Gems, curly-dwarf Green Mountains, and curly-dwarf Irish Cobblers. The third generation of representative parts of Series 8 and 19 were grown in 1922, a season unusually favorable for the detection of mosaic mottling. Series 8 contained leaf-rolling mosaic, rugose mosaic, spindling-tuber disease, and various combinations including mottled curly dwarf in the majority of the tuber units, with the controls mostly healthy. Series 19 consisted almost entirely of unmottled curly-dwarf plants (p. 60), with the controls mostly healthy. It is to be concluded that the open-field leaf-mutilation inoculations in 1920 at least transmitted rugose mosaic, a combination of leaf-rolling mosaic and spindling-tuber disease, and unmottled curly-dwarf.

Inoculation series.[1]	Diseased plants, source of inoculum.				Inoculated plants.				Controls.			
	Variety.	Parents.		Progeny, 1921.	1920	Progeny, 1921.			1920	Progeny, 1921.		
		1919	1920		Hills.	Tuber units.	Mosaic.	Curly dwarf.	Hills.	Tuber units.	Mosaic.	Curly dwarf.
							Per cent.	Per cent.			Per cent.	Per cent.
1	Russet Rural	Healthy	Healthy	Healthy	10	49	0	0	10	47	0	0
2	....do	Curly dwarf	Curly dwarf	Curly dwarf	8	38	29	0	8	39	36	0
3-4	....do	....do	....do	....do	[2]4	22	5	0	[2]4	(?)	0	0
5	....do	Mosaic	Mosaic	Apparently healthy.	10	48	67	6	9	43	7	12
6	Green Mountain		....do		8	48	4	2	8	50	0	0
7	Netted Gem	Healthy	Dwarfing and wrinkling.		8	37	0	84	8	38	5	0
8	Non Blight [3]	Curly dwarf	Curly dwarf	Curly dwarf	6	29	69	0	6	25	0	0
9	Uncle Sam [3]	....do	....do	....do	10	48	6	6	10	50	8	6
10	Rural New Yorker No. 2.	....do	....do	....do	10	43	0	2	10	46	4	4
11	Carman No. 3 [3]	....do	....do	....do	10	47	0	0	10	41	0	0
12	Prince Henry [3]	....do	....do		10	47	0	4	10	47	0	0
13	Radish, control		Healthy		10	39	2	2	9	43	4	0
14	Carman No. 3 [3]	Mosaic	Mosaic	Apparently healthy.	9	43	0	0	10	50	8	8
15	Green Mountain	Healthy	....do		6	30	0	0	6	26	4	0
16	....do	....do	....do		6	22	23	0	6	28	25	0
17	Prince Henry [3]	Mosaic	....do	Apparently healthy.	10	41	0	0	10	42	2	0
18	Dearborn [3]	Curly dwarf	Curly dwarf	Mosaic dwarf	8	37	0	0	6	26	0	11
19	Green Mountain	Dwarfing, streaking.	....do		8	32	0	63	6	29	0	0
20	....do	Healthy	Mosaic		4	15	0	0	4	17	0	0
66	Irish Cobbler	....do	Curly dwarf	Curly dwarf	10	44	0	66	10	50	0	0

[1] Given numerical order corresponding with chronological order of performance.
[2] Grown under insect cages.
[3] Of the Rural type when observed as healthy hills in the same lots in 1919.

TABLE XIII.—*Intervarietal inoculations of Green Mountains performed with aphids dispersing from diseased to healthy plants in insect cages in 1920*

Cage No.	Variety.	Diseased plants, source of inoculum. Parent plants, 1919.	Diseased plants, source of inoculum. 1920	Diseased plants, source of inoculum. 1921	Inoculated plants. Parent plants, 1919.	Inoculated plants. 1920	Inoculated plants. 1921	Controls. 1920	Controls. 1921
1	Non Blight [1]	Curly dwarf	Curly dwarf	Curly dwarf	None	None	Mosaic in 40 per cent, wrinkling in 80 per cent.	Healthy	Healthy.
2	Sensation [1]	do	do	do	do	do			
3	Uncle Sam [1]	do	do	do	do	do	do	do	Do.
4	Rural New Yorker No. 2.	do	do	do	do	Chlorosis	Wrinkling in 50 per cent.	do	Do.
5	Carman No. 3 [1]	do	do	do	do	do	Wrinkling in 83 per cent.	do	Do.
6	Dearborn [1]	do	do	do	do	None	Mosaic in 33 per cent, wrinkling in all.	do	Do.
7	Seedling		Dwarfing, wrinkling, and rugosity.	Dwarfing, wrinkling, and rugosity.	do	do	Healthy	do	Do.
8	Green Mountain	None	Curly dwarf	Dwarfing, chlorosis, brittleness, and burning.	do	do	do	do	Do.
9	Seedling		Wrinkling, rugosity, and slight streaking.	do	do	do	do	do	Do.
10-14	Green Mountain	Mosaic	Mosaic	Dwarfing, wrinkling, and burning.	do	do	Mosaic in 83 per cent.	do	Do.

[1] Of the Rural type when observed as healthy hills in the same lot in 1919.

During the same season, in each of nine field insect cages (No. 1 to 9 of Table XIII), a Green Mountain plant was grown between two plants that were of another variety and that apparently were diseased. Cages 10 to 14 contained comparison inoculations from mild mosaic Green Mountains. In June, potato aphids were transferred from rose bushes (36) to healthy potato plants (in entirely healthy tuber units and caged) and in July from these to the cages used in this experiment. The aphids were allowed to disperse freely within the cages. Sister hills in the same tuber units were grown under separate insect cages as controls, and were not inoculated. The results are given in Table XIII. It is of interest that inoculations 1, 2 and 5, were successful in inducing mosaic in the progeny, although the source of the inoculum was curly-dwarf plants. Furthermore, inoculations 1, 3, 4, and 6 in the insect cages (Table XIII) were, respectively, duplicates in a measure of the open-field inoculation Series 8, 9, 10, and 18 (Table XII). That is, the source of the inoculum in each pair of corresponding inoculations was the same stock of potatoes. The first of these four sources yielded inoculum that was ineffective with either method of inoculation, but not the others. This indicates that it was the nature of the inoculum rather than the method of inoculation that determined the success secured in the attempts at infection. The recording of more mosaic in the progeny of the caged hills than of the open-field hills is correlated with more frequent examination, made desirable by the limited number of caged hills and the expense of cage experimentation and possibly with more favorable conditions for infection the preceding season. Even so, the symptoms were not very distinct or extensively distributed over the plants.

Further open-field leaf-mutilation inoculations were made in 1920 with the inoculum taken from leaf-roll Irish Cobblers to Green Mountains in two hills of each of six four-hill tuber units, with negative results in both generations.

INOCULATIONS PERFORMED IN 1921

In 1921 the leaf-mutilation method was used again with inoculum obtained from several sources. The inoculum in each series was applied to two or more varieties, and with the exceptions of Series 1 and 7 was unrenewed—that is, the juice was expressed from a certain group of shoots at one time. The inoculated plants were in rows of 11 four-hill tuber units. One hill in each unit was inoculated with juice from mosaic Bliss Triumph plants and another with juice not alike, in regard to source, for two rows of any one variety. The date of inoculation was from July 4 to July 9, except for Series 6 and 8, for which it was July 19. Additional data are given in Table XIV. The current-season symptoms make it evident that the inoculum used in Series 1 to 5 was very infective and injurious, while that used in Series 6, 7, and 10 was apparently without effect. In general, the effects of inoculation in Series 1, 2, and 3 were similar, being those of rugose mosaic in the upper part of the plant, with the mottling fading, as often occurs, into diffused chlorosis with greater degree of maturity (Pl. 12, C). The effects of inoculation in Series 5 were different, being those of streak in the upper part of the plant (Pl. 5, A, C). Series 4 gave effects of both rugose mosaic and streak.

The second-season symptoms in 1922 are also noted in Table XIV. No distinction was attempted between the progeny of inoculated and uninoculated hills as to the spindling-tuber disease in any of the three varie-

ties or as to mild mosaic in Green Mountains, for reasons given in the footnotes. It was obvious that rugose mosaic had been transmitted to all three varieties from Rurals, and from two seedling varieties to two inoculated varieties (Series 1, 2, and 3), and that streak and the streak combination with rugose mosaic, after transmission and tuber perpetuation, were much worse in their effects than rugose mosaic alone. Leaf-roll was not transmitted. Leaf-rolling mosaic from the Rurals (Series 1) was combined with spindling-tuber disease, giving mottled curly dwarf.

The conclusions from this experiment are that leaf-roll was not transmissible under the prevailing conditions; that mild mosaic and spindling-tuber disease were present and uncontrolled; that leaf-rolling mosaic was transmitted from curly-dwarf Rurals in combination with rugose mosaic and possibly with spindling-tuber disease, being combined with the latter in Green Mountains to form mottled curly-dwarf; that rugose mosaic was transmitted from four dissimilar symptom complexes in three varieties; and that streak, both alone and with rugose mosaic, was transmitted and was perpetuated by the tubers, with effects in the second generation similar for the single and combined state and at the same time unlike the effects in the first generation.

Several other interesting facts may be noteworthy. In a number of tuber units (Table XIV, rows 1–B, 1–D, and 2–J), mosaic was perpetuated by the seed tuber and was present when a more severely injurious disease was introduced to some of the hills. The inoculated hills (not described in Table XIV) became different from the others in these units after the incubation period, and the original mosaic symptoms were somewhat obscured. In Series 1 and 3 the Irish Cobblers showed fine or small spotting, but not the Green Mountains. Such spotting is common on Irish Cobblers which are found diseased as the result of natural field infection, presumably following rugose-mosaic transmission by insects. In Series 1 the Rurals showed streaking which was not in the other varieties, but they were inoculated with juice taken two days later from different hills in the same lot, so a different virus may have been present. Variation in completeness of symptom complexes in the same row following the introduction of the same inoculum was observed, as described in Table XV. Such variation may be due only to differences in the size of the plants at the time of inoculation, and therefore be due to the leaf-surface conditions of inoculation rather than to differences in the inherent nature of the plants.

TABLE XIV.—*Leaf mutilation inoculations of Green Mountains and other varieties performed in the open field in 1921*

Inoculation series.	Diseased plants, source of inoculum. Variety.	Parent plants, 1920.	1921	Inoculated plants, 1921. Variety.	Row.	Hills	Symptoms.	Uninoculated controls, 1921. Hills	Symptoms.	Remarks, 1921.	Progeny of inoculated plants, 1922.	Progeny of uninoculated controls, 1922.
1	Carmen No. 3 [a]	Curly dwarf.	Curly dwarf.	Green Mountain.	1-B	7	Mosaic in upper leaves of some stalks by July 23, in 6 hills, chlorosis becoming diffused by Aug. 23, with brittleness and burning. One hill healthy at first but like others by Aug. 23, except not brittle.	14	None	Four tuber units mosaic.	Rugose mosaic, leaf-rolling mosaic, and spindling-tuber disease in different combinations.	No rugose or leaf-rolling mosaic.[b]
				Irish Cobbler	2-B.	11	Mosaic in upper leaves of some stalks by July 23, in 3 hills, with fine spotting by Aug. 1. Dwarfing, brittleness, chlorosis, and burning in 9 hills by Aug. 23, with wrinkling in 6 hills and fine spotting in 5 hills. One hill mottled and one healthy on Aug. 23.	22	....do		Rugose mosaic [c].	No rugose mosaic.[c]
				Rural New Yorker.	3-B.	11	Mosaic and streaking in upper leaves in 7 hills by Aug. 1. On Aug. 23, 6 hills with dwarfing, brittleness, chlorosis, and burning, including 2 hills with mottling, streaking, and wrinkling also; 2 hills with mottling, streaking, and wrinkling above; 3 hills healthy.	22	....do		....do	Healthy.[d]
2	Seedling 41016.		Slight dwarfing, rugosity.	Green Mountain.	1-O.	10	Mosaic in upper leaves by July 23, with leaf dropping by Aug. 1, in all hills. On Aug. 23, mostly like hills of row 1-B (Table XV).	20	....do		....do	No rugose mosaic.[b]
				Irish Cobbler	2-O.	11	As for row 1-O except more like row 1-B finally.	22	....do		....do [c]	Do [c]

[a] Inoculum taken two days later for the Rurals, and from different hills than for the other two varieties.
[b] Much mild mosaic and spindling-tuber disease in this variety in these progeny.
[c] All spindling tuber in this variety in these progeny.
[d] No attempt to diagnose spindling-tuber disease in this variety in these progeny.

TABLE XIV.—*Leaf-mutilation inoculations of Green Mountains and other varieties performed in the open field in 1921*—Continued

Inoculation series	Diseased plants, source of inoculum. Variety.	Diseased plants, source of inoculum. Parent plants, 1920.	Diseased plants, source of inoculum. 1921	Inoculated plants, 1921. Variety.	Inoculated plants, 1921. Row.	Inoculated plants, 1921. Hills.	Inoculated plants, 1921. Symptoms.	Uninoculated controls, 1921. Hills	Uninoculated controls, 1921. Symptoms.	Remarks, 1921.	Progeny of inoculated plants, 1922.	Progeny of uninoculated controls, 1922.
3	Seedling 41016.	....	Slight dwarfing, burning.	Green Mountain.	1-H	11	As for row 1-O except leaf dropping not present until after Aug. 1 (Table XV).	22	None	....	Rugose mosaic	No rugose mosaic.[a]
				Irish Cobbler	2-H	11	Nine hills as for row 2-B. Two hills healthy July 23, but on Aug. 23, like others with fine spotting still showing.	22	do	....	do.[b]	Do.[b]
4	Seedling 41186.	....	Mosaic dwarf.	Green Mountain.	1-D	9	Eight hills mosaic in upper leaves by July 23, with spotting in 6 hills, and with leaf dropping, spotting, and streaking by Aug. 1; dead by Aug. 23. One hill healthy at first but with brittleness, streaking, and burning by Aug. 23.	17	Three hills mosaic.	Two tuber units mosaic.	Severe dwarfing and early death; second season streak symptoms.	No dwarfing.[a]
				Irish Cobbler	2-D	11	All hills mosaic in upper leaves by July 23, with spotting or streaking or both. By Aug. 23, either dead or like row 2-B.	22	None	....	do.[b]	Do.[b]
5	do	....	Streak	Green Mountain.	1-J	10	Spotting and streaking in 5 hills by July 23, and in 8 hills by Aug. 1, with death of upper parts of some shoots. Six hills dead by Aug. 23, and 3 hills with brittleness, burning, spotting, and streaking.	19	do	....	do	Do.[a]
				Irish Cobbler	2-J	10	As for row 1-J except 9 hills affected by July 23 and all hills by Aug. 1, and 8 hills dead on Aug. 23.	22	do	One tuber unit mosaic.	do.[b]	Do.[b]

				Irish Cobbler	2-Q	11	....do	33	One hill streak in part.	saic.	No mosaic.[b]	No mosaic.[b]
6	Green Mountain.	Part mosaic	Mosaic	Rural New Yorker.	3-J	11	....do	33	None		Healthy[c]	Healthy.[c]
				Inoculated controls.[d]	Inoculated controls.[d]	110	....do	[e] 0			No rugose mosaic.[a b]	No rugose mosaic.[a b]
7	Bliss Triumph.	Mosaic	Mosaic	Bliss Triumph.	3-N	9	....do	27	....do		Healthy[c]	Healthy.[c]
8	....do.[f]		....do	Green Mountain.	Cages M-1, 2.	6	Mosaic in upper leaves of 2 hills	6	....do		28 per cent mild mosaic.	Do.
				....do	1-D	9	Mosaic in upper leaves of 2 hills (field infection).	8	Mosaic in part in 1 hill.		No rugose mosaic.[a]	No rugose mosaic.[a]
9	Water controls.			Irish Cobbler	2-D	11	None	11	None		....do.[b]	Do.[b]
				Rural New Yorker.	3-C	11	....do	33	....do		....do.[c]	Do.[c]
				Green Mountain.	1-F	11	....do	22	....do		No leaf roll[a]	No leaf roll.[a]
10	Irish Cobbler	Leaf roll	Leaf roll	Irish Cobbler	2-F	11	....do	22	....do		....do.[b]	Do.[b]
				Rural New Yorker.	3-N	?	....do	?	....do		....do.[c]	Do.[c]

[a] Much mild mosaic and spindling-tuber disease in this variety in these progeny.
[b] All spindling tuber in this variety in these progeny.
[c] No attempt to diagnose spindling-tuber disease in this variety in these progeny.
[d] Hills adjacent to those inoculated in series 1 to 5.
[e] Same as for series 1 to 5.
[f] The same unrenewed inoculum that was used without visible effects on hills in row 3-N (Bliss Triumph), 1-M (Green Mountain), and 2-M (Irish Cobbler).

TABLE XV.—*Symptoms of inoculated hills of rows 1–O and 1–H of Table XII, August 23*

Row.	Tuber unit.	Dwarfing.	Chlorosis.	Mottling.	Wrinkling.	Rugosity.	Ruffling.	Curling.	Rolling.	Uprightness.	Rigidity.	Brittleness.	Spotting.	Streaking.	Burning.	Leaf dropping.
1–O	1	+	+	....	+	....	....	....	....	....	....	+	....	....	+	+
	2	+	+	....	+	....	....	....	....	....	....	+	....	....	+	+
	3	+	....	+	+	....	....	....	....	....	....	....	....	....	+	+
	4	+	....	+	+	....	....	+	....	....	....	+	....	....	+	+
	5	+	....	+	+	....	....	....	....	....	....	....	....	....	+	+
	6	+	....	+	+	....	....	....	....	....	....	+	....	....	+	+
	7	+	+	....	+	....	....	....	....	....	....	....	....	....	+	+
	8	+	+	....	+	....	....	....	....	....	....	+	....	....	+	+
	9	+	+	+	+	....	....	....	....	....	....	....	....	....	+	+
	10	+	....	+	+	....	+	....	....	....	....	+	....	....	+	+
1–H	1	+	....	+	+	....	....	....	....	....	....	+	....	....	+	+
	2	+	+	....	+	....	....	....	....	....	....	+	....	....	+	+
	3	+	+	....	+	....	....	....	....	....	....	+	....	....	+	+
	4	+	....	+	+	....	....	....	....	....	....	+	....	....	+	+
	5	+	+	....	+	....	....	+	....	....	....	....	....	....	+	+
	6	+	+	+	+	....	....	....	....	....	....	+	....	....	+	+
	7	+	+	+	+	....	+	....	....	....	....	+	....	....	+	+
	8	+	....	+	+	....	+	....	....	....	....	....	....	....	+	+
	9	+	....	+	+	....	....	+	....	....	....	....	....	....	+	+
	10	+	....	+	+	....	+	....	....	....	....	....	....	....	+	+
	11	+	....	+	+	....	....	+	....	....	....	....	....	....	+	+

In connection with the preceding experiment, duplicates of many the leaf-mutilation inoculations were made with capillary glass tubes. From three to five of these tubes were filled with the juice and inserted into each shoot in the leaf axils (Pl. 13, B). This method was effective only in the rows corresponding to 1–O, 2–O, and 1–J (Table XIV), and there only in a few hills, with symptoms appearing later than in the case of leaf mutilation. Apparently, transmission is too difficult with this method to be dependable, at least in comparison with the leaf-mutilation method.

Corresponding inoculations of caged Green Mountains and Irish Cobblers with potato aphids, with contact of roots and foliage, were made in 1921. Six tubers of each variety were quartered. The quarters from each tuber were grown, respectively, in cages of four series—with no inoculation, with inoculation from mosaic Green Mountain hills, with inoculation from curly dwarf hills, and with inoculation from progeny of streak hills. In the first series there were three healthy plants in a cage, in the second there were two healthy and one diseased in a cage, and in the two others one healthy and two diseased. The aphids were transferred to the diseased plants and in turn reached the healthy plants in the same cages. The latter were planted somewhat later than the former so that they were still small when aphids were numerous enough to disperse and to be transferred artificially. Some of the diseased plants in the streak series were removed on account of the appearance of mottling and the cages used for other experiments. This experiment is described further in Table XVI.

Inoculation No.	Diseased plants, source of inoculum. Variety.	Parent plants, 1920.	1921	1922.[a]	Inoculated plants. Variety	Parent plants, 1920.[b]	1921	1922.[a]
1	Russet Rural	Curly dwarf	Curly dwarf	Curly dwarf	Green Mountain	Healthy	Mosaic in upper leaves	5/5 leaf-rolling mosaic.
			do	do	Irish Cobbler	do	Healthy	1/2 dwarfed.
			do	do	Green Mountain	do	Mosaic in upper leaves	5/5 leaf-rolling mosaic (Pl. 2, C, 1).
2	Uncle Sam[c]	do	do	do	Irish Cobbler	do	Healthy	2/3 wrinkled.
3	Rural New Yorker No. 2.	do	do	do	Green Mountain	do	do	1/11 leaf-rolling mosaic.
			do	do	Irish Cobbler	do	do	2/2 dwarfed.
4	Irish Cobbler	do	do	Dwarfed	Green Mountain	do	do	1/3 unmottled curly dwarf (Pl. 10, A, 2).
5[d]	Green Mountain	Mosaic and spindling tuber[b]	Mosaic and spindling tuber.	Mild mosaic and spindling tuber.	do	do	do	6/19 mild mosaic; 5/19 spindling tuber.
6	do	do	do	do	Irish Cobbler	do	do	Healthy.
7	Seedling 39496	Curly dwarf	Dwarfing, leaf dropping, and premature death.	Dwarfing	Green Mountain	do	Mosaic in upper leaves of part, and later streaking also.	2/6 rugose mosaic (Pl. 4, A, 1).
			Dwarfing, mottling, brittleness, leaf dropping, and premature death.	do	Irish Cobbler	do	Streaking	1/2 rugose mosaic.
8	Green Mountain	do	Curly dwarf	Leaf-rolling mosaic and spindling tuber (curly dwarf combination).	Green Mountain	do	Healthy	1/3 spindling tuber; 2/3 spindling tuber and leaf-rolling mosaic (curly dwarf combination (see Pl. 3, A, B).
			do	do	Irish Cobbler	do	do	2/2 wrinkled.
9	do	do	do	Dwarfed	do	do	do	6/6 wrinkled.
10	Seedling 39374	Streaking	Mosaic	Rugose mosaic	Green Mountain	do	do	6/6 healthy.
			do	do	Irish Cobbler	do	do	Healthy.
11	Seedling 39937	do	Dwarfing, rugosity, brittleness, burning.	Curly dwarf and rugose mosaic.	Green Mountain	do	Mosaic in upper leaves, becoming mosaic-dwarf.	4/4 leaf rolling and rugose mosaic.
			do	do	Irish Cobbler	do	do	4/4 rugose mosaic.
12	Seedling 40203	do	Dwarfing, chlorosis, rugosity, burning.	Dwarfed, rugose	Green Mountain	do	Mosaic in upper leaves.	2/2 leaf-rolling and rugose mosaic.
			Chlorosis	do	Irish Cobbler	do	Healthy	5/5 dwarfed.
13	Charles Downing		Streaking	Rugose mosaic	Green Mountain	do	do	4/4 spindling tuber.
	Irish Cobbler		Spindling tuber	Spindling tuber				
14	Green Mountain	Streaking	Mosaic	5/5 mild mosaic; 3/5 spindling tuber	do	do	Mosaic in upper leaves.	4/4 mild mosaic and spindling tuber (see Pl. 8, B).
					Irish Cobbler	Spindling tuber.	Spindling tuber	2/2 wrinkled and spindling tuber.

[a] Mostly 2-hill tuber units. [b] Caged and not inoculated. [c] Of the Rural type when observed as healthy hills in the same lot in 1919. [d] Also described in Table II.

48108—23——3

Current-season symptoms appeared in some of the cages in which the disease present was curly dwarf (inoculation Series 1 and 2, Table XV) and in one of the cages in which the disease was mosaic (No. 14), resulting in mosaic in the upper leaves. Mosaic also resulted from No. 12 in which the symptoms were dwarfing, chlorosis, rugosity, and burning, from No. 11 in which there were dwarfing, brittleness, rugosity, and burning, and from No. 7 in which there were dwarfing, leaf dropping, and premature death. However, in No. 11 the final effect was mosaic-dwarf, and in No. 7 it was a combination of mosaic and streaking. Inoculation was effective in the Irish Cobblers only in No. 11 and 7, the results being similar to those in the other variety except for the absence of mosaic in No. 7.

The second generation was planted in the open field and the symptoms are also given in Table XVI except that all the inoculated Irish Cobblers were spindling tuber and likewise the controls in this variety. The Green Mountain controls were all healthy. It appears that the inoculation of Green Mountains resulted in the transmission of leaf-rolling mosaic in No. 1, 2 (Pl. 2, C, 1,), and 3, from curly dwarf Rurals; of rugose mosaic in No. 7 from dwarfed seedling variety 39496 (Pl. 4, A); of spindling-tuber disease in No. 5, 8 (Pl. 3, B, 1) and 13 from spindling-tuber Green Mountains and Irish Cobblers; of mild mosaic in No. 5 from mild mosaic Green Mountains; of unmottled curly dwarf in No. 4 from Irish Cobblers (Pl. 10, A, 2,) and of various combinations of these four diseases in No. (Pl. 3, B), 11, 12, and 14 (Pl. 8, B). It is noteworthy that with early transmission and consequent more current-season symptoms in 192 there was more complete infection of the progeny in 1922. Infection in the Irish Cobblers, already spindling tuber, was not so apparently successful. In inoculations No. 1, 2, 3, 4, 7, and 12, the leaf-rolling mosaic, rugose mosaic, or unmottled curly dwarf symptoms induced in the Green Mountains were not like the symptoms in the source of inoculum hills or their progeny, suggesting varietal modification and masking of symptoms, especially of mosaic (Pl. 2, C; 4, A). The inoculated hills in No. 7, the parents of the diseased hills in No. 10 and 14, and the Charles Downing diseased hill in No. 13, showed streaking which was replaced in the following generations by rugose mosaic or by mild mosaic in combination with spindling-tuber disease.

INOCULATIONS PERFORMED IN 1922

In the field, during 1922, leaf-mutilation inoculations with different types of mosaic, with leaf roll, and with spindling tuber were made on plants of the Green Mountain, Irish Cobbler, Bliss Triumph, and Rural New Yorker varieties. The method of planting, in 4-hill tuber units resembled that of previous seasons. One or two hills in a tuber unit, either the second and third hill, or the third hill alone, were treated so that two or three uninoculated controls were in each inoculated tuber unit. Single applications were made in each series with the exception of Series 58, 59, and 60, in which the second hill in each unit received two inoculations, and with the exception of mild mosaic and leaf roll, where three repeated applications were made. The positive current-season results of these inoculations are presented in Table XVII.

Inoculations with mild mosaic and leaf roll are not indicated in this table, since no current-season symptoms appeared. Infection from inoculations made under cages with mild mosaic by leaf mutilation is described in Table XVIII. Inoculations with spindling tuber were discussed in Table VII.

Inoculation series.[1]	Source of inoculum. Variety.	Source of inoculum. Symptoms. Parents, 1921.	Source of inoculum. Symptoms. Diseased plants, 1922.	Inoculated plants. Variety.	Inoculated plants. Row.	Inoculated plants. Hills.	Inoculated plants. Symptoms.[2]	Uninoculated controls. Hills.	Uninoculated controls. Symptoms.
10	Green Mountain	Rugose mosaic and streak.[3]	Severe dwarfing and early death.	Green Mountain	2; sec. 8	5	Rugose mosaic and streak	15	Healthy.
11				Irish Cobbler	2; sec. 7	5	do	15	No rugose mosaic or streak.
12				Bliss Triumph	1; sec. 6	5	Rugose mosaic and streak in 2 hills	15	Do.
14	do	Streak[4]		Green Mountain	2; sec. 8	5	Streak	15	No streak.
15				Irish Cobbler	2; sec. 7	5	Streak in 3 hills	15	Do.
16				Bliss Triumph	1; sec. 6	5	Streak in 4 hills	15	Do.
18	do	Rugose mosaic[5]	Leaf-rolling mosaic and spindling tuber (curly dwarf).	Green Mountain	3; sec. 8	5	Rugose mosaic and streaking	15	No streaking; 2 hills rugose mosaic.
19				Irish Cobbler	3; sec. 7	5	do	15	No rugose mosaic or streaking.
29				Bliss Triumph	2; sec. 6	5	Rugose mosaic and streaking in 3 hills.	15	Do.
58	do	do	Rugose mosaic	Green Mountain	9; sec. 8	10	Rugose mosaic	10	No rugose mosaic.
59				Irish Cobbler	9; sec. 7	10	do	10	Do.
60				Bliss Triumph	8; sec. 6	10	Rugose mosaic in 9 hills	10	Do.
79	do	Rugose mosaic[6]	Bad mosaic and spindling tuber.[7]	Green Mountain	11; sec. 8	5	Rugose mosaic in 3 hills	15	Do.
80				Irish Cobbler	11; sec. 7	5	do	15	Do.
81				Bliss Triumph	9; sec. 6	5	Rugose mosaic and streaking in 3 hills	15	Do.
83	Rural New Yorker	Dwarfing and leaf rolling.	Rugose mosaic and leaf-rolling mosaic.	Green Mountain	12; sec. 8	5	Rugose mosaic	15	Do.
84				Irish Cobbler	12; sec. 7	5	Rugose mosaic in 3 hills	15	Do.
85				Bliss Triumph	10; sec. 6	5	Rugose mosaic and streaking	15	Do.
87	Green Mountain	Rugose mosaic[8]	Rugose mosaic	Green Mountain	12; sec. 8	5	Rugose mosaic	15	Do.
88				Irish Cobbler	12; sec. 7	5	do	15	Do.
89				Bliss Triumph	10; sec. 6	5	Rugose mosaic and streaking in 4 hills	15	Do.
105	Seedling 39374		Dwarfing; no mottling.	Green Mountain	15; sec. 8	5	Rugose mosaic and streaking	15	Do.
106				Irish Cobbler	14; sec. 7	5	do	15	Do.
107				Rural New Yorker	12; sec. 5	5	Streak in 3 hills	15	No streaking.

[1] Each group of consecutive numbers represents a group of series with identical inoculum.
[2] In all inoculated plants, unless number is stated.
[3] Row 1-D of Table XIV.
[4] Row 1-J of Table XIV.
[5] Row 1-B of Table XIV.
[6] Row 1-H of Table XIV and Table XV, tuber unit 9.
[7] Thought to contain leaf-rolling mosaic as well as rugose mosaic.
[8] Row 1-H of Table XIV and Table XV, tuber unit 10.

TABLE XVII.—*Leaf-mutilation inoculations of Green Mountain and other varieties, performed in the open field in 1922*—Continued.

Inoculation series.[1]	Source of inoculum. Variety.	Source of inoculum. Symptoms. Parents, 1921.	Source of inoculum. Symptoms. Diseased plants, 1922.	Inoculated plants. Variety.	Inoculated plants. Row.	Inoculated plants. Hills.	Inoculated plants. Symptoms.[2]	Uninoculated controls. Hills.	Uninoculated controls. Symptoms.
123	Seedling 39374		Rugose; leaf dropping.	Green Mountain	20; sec. 8	5	Rugose mosaic and streaking	15	No rugose mosaic and no streaking.
124				Irish Cobbler	15; sec. 7	5	....do	15	Do.
127	Green Mountain		Bad curly dwarf and leaf dropping.	Green Mountain	21; sec. 8	5	Rugose mosaic and streaking in 3 hills	15	Do.
128				Irish Cobbler	16; sec. 7	5	Rugose mosaic and streaking	15	Do.
130	Seedling 41451		Streak and slight rugosity on young leaves.	Green Mountain	21; sec. 8	5	Rugose mosaic and streaking in 3 hills	15	Do.
131				Irish Cobbler	16; sec. 7	5	Rugose mosaic and streaking	15	Do.
133	Seedling		Streaked and no apparent mottling.	Green Mountain	22; sec. 8	5	Rugose mosaic and streaking in 2 hills	15	Do.
111	Rural New Yorker		Curly dwarf	....do	16; sec. 8	5	Rugose mosaic and streaking	15	Do.
119	....do		Curly dwarf; mottled.	....do	18; sec. 8	5	Rugose mosaic and streaking in 4 hills.	15	Do.

[1] Each group of consecutive numbers represents a group of series with identical inoculum.
[2] In all inoculated plants, unless number is stated.

s indicated in Table XVII, the current-season reactions of the varie- inoculated with juice from vines showing different types of mosaic, rf, and streak symptoms, were rugose mosaic and streak or combi- ions of these. Streak alone resulted from inoculations with juice m a Green Mountain lot inoculated in 1921 with juice from a streak nt in a seedling variety (Series 14, 15, and 16). Streak, therefore, appeared without apparent combinations in three succeeding gener- ons, including two in Green Mountains and Irish Cobblers as the result leaf-mutilation inoculation. As indicated, the second generation nts used as source of inoculation for streak in 1922, were badly arfed and died early—before tuber formation. Similar phenomena re obtained with the progeny of plants inoculated in 1921, with juice m a mosaic dwarf plant adjacent to the streak plant, of the seedling riety, mentioned above (Series 10, 11, and 12). Here some of the culated hills produced stalks showing streak alone and rugose mosaic one, as well as a combination of these symptoms, suggesting that saic-dwarf in the original seedling plant may have been a combination rugose mosaic and streak, the severe dwarfing being due mainly to eak in the combination. These two inoculations are different from e others in that they produced streak alone in Green Mountains and sh Cobblers while the others produced rugose mosaic in close associa- on with any streaking seen in these varieties. They are also different cause the source of inoculum was extremely dwarfed plants quite like the plants, with rugose mosaic or other symptom complexes, that rved as sources of inoculum for the other inoculations.

It seems probable that streaking may be a prominent first-season mptom of two diseases—streak and rugose mosaic—and not always a gn of streak. This view of the uncertain value of the one symptom of reaking as a sign of the symptom complex or disease of streak is ointed out by Orton (*33, p. 100*), and is supported by the writers' omparison of first-season and second-season symptoms in a number of ts with rugose mosaic the second season. Streaking was more common s an apparent first-season symptom of rugose mosaic in Bliss Triumphs nd Rurals (Table XVII, Series 81, 85, 89, and 107). Whether other iseases in several combinations used here (Series 18 to 20, 79 to 81, 83 o 85, and perhaps others) were transmitted along with rugose mosaic nd merely did not show current-season symptoms, can be learned only rom the second generation in 1923. The consistent emergence, from ombinations, of rugose mosaic in 1922, indicates that the other diseases, whether also transmitted or not, were of a less virulent type. Modifica- ion of rugose mosaic symptoms in combination with other diseases ccurred in Series 10 to 12, 18 to 20, 79 to 81, and 127 to 128. The same thing, or else varietal modification of rugose mosaic symptoms, was shown n Series 105 to 107, 123 to 124, 130 to 131, 133, 111, and 119.

In addition to those in the open field, other leaf-mutilation inoculations were made in insect cages located in the same field. As indicated in Table XVIII, repeated inoculations with mild mosaic and spindling- uber were made in Series A–III and B–III, while but a single application was made in the remaining series, which included juice from mosaic dwarf and streak as well as from mild mosaic and spindling-tuber plants. Plants for the source of mild mosaic and spindling-tuber inoculum, were rown in cages since 1920, inclusive, and for mosaic dwarf and streak ince 1921. As indicated, three different varieties and one seedling were

TABLE XVIII.—*Leaf-mutilation inoculations of Green Mountain and other varieties performed in insect cages in the field in 1922*

Inoculation series.	Source of inoculum.			Inoculated plants.			Uninoculated controls.	
	Variety.	Symptoms.		Variety.	Hills.	Symptoms.	Hills.	Symptoms.
		Parents, 1921.	Diseased plants, 1922.					
A-III [1]	Green Mountain	Mild mosaic and spindling tuber.	Mild mosaic and spindling tuber.	Green Mountain	3	Mild mosaic; spindling and flat, oblong tubers in each hill.	3	No mosaic and no spindling tuber.
B-III [1]	do	do	do	Irish Cobbler	3	No apparent mottling; spindling tubers in hills 1 and 2; normal and spindling tubers in hill 3.	3	No apparent mottling; spindling tubers in hills 1 and 2; normal tubers in hill 3.
E-III	do	do	do	Green Mountain	3	Mild mosaic and spindling tuber in hill 3 (Pl. 9, B, 2); hills 1 and 2 healthy.	3	Healthy.
F-III	do	do	do	Irish Cobbler	3	No apparent mottling; normal tubers in hill 1; spindling tubers in hill 2; spindling and normal in hill 3.	3	Apparently healthy plants in hills 1 and 3; spindling tubers in hill 2.
G-III	do	do	do	Seedling 39374	3	No apparent mottling	3	Healthy.
H-III	do	do	do	Bliss Triumph	3	do	3	Do.
E-II	do	do	Mosaic dwarf	Green Mountain	3	Rugose mosaic	3	Do.
F-II	do	do	do	Irish Cobbler	3	Healthy	3	Do.
G-II	do	do	do	Seedling 39374	3	Spotting and streaking on hill 3	3	Do.
H-II	do	do	do	Bliss Triumph	3	Healthy	3	Do.
E-I	Seedling 39374	Streak	Streak	Green Mountain	3	do	3	Do.
F-I	do	do	do	Irish Cobbler	3	do	3	Do.
G-I	do	do	do	Seedling 39374	3	Streak and mottling	3	Do.
H-I	do	do	do	Bliss Triumph	3	Healthy	3	Do.

[1] 3 inoculations at weekly intervals; 1 inoculation on remaining series.

culated in comparative series. The average height of the plants at time of the first inoculation was about 7 cm.

Repeated applications with mild mosaic and spindling tuber were re effective than single treatments. The Irish Cobbler apparently ows greater susceptibility to spindling tuber than to mild mosaic. distinct varietal reaction to mosaic dwarf appears between Green untain and seedling 39374, being rugose mosaic or streaking and tting, respectively, suggesting the combination for mosaic dwarf to be gose mosaic and streak. The occurrence of spindling tuber in the conls in the Irish Cobbler variety resulted from field infection in 1921. ce in each series, hills 1, 2, and 3 in the inoculated lot are progeny m seed pieces of the same three tubers, respectively, as hills 1, 2, and of the control lot, it is quite apparent that spindling-tuber infection ulted from inoculation in some units in which the controls remained althy (Series A–III, all three hills; B–III, hill 3; E–III, hill 3 (Pl. 9,); F–III, hill 3.)

INTERVARIETAL INOCULATIONS IN THE GREENHOUSE

Results previously reported from greenhouse experiments on interrietal inoculations consist of the transmission of mosaic by juice ansfer from Green Mountains to Bliss Triumphs (*45, p. 253–55*), and leaf roll by aphid dispersal from both Green Mountains and Irish Coblers to each of these varieties (*41, p. 57–58*).

In the Orono greenhouse in the winter of 1920–21, mild mosaic inocutions of Green Mountains were made with several juice-transfer methods Table XIX, Series 1 to 10). The inoculum was always obtained from ild mosaic Bliss Triumph hills.

It will be noted in Table XIX that in Series 1 to 7 inoculation of any ype was performed at four different times. The inoculated plants in his experiment were potted separately but consisted of 4-hill tuber units. The four plants grown from any one tuber were inoculated, respectively, t the four different times which were not absolute dates but corresponded o certain stages of development of the plant. The first plant to reach a height of 10 to 15 cm., or Stage I, was inoculated immediately. All four plants were observed in regard to the time when the terminal shoot exposed the first flower-bud cluster by opening and growing beyond it, and this was considered as the anthesis stage (II) since all potato buds abort in the Orono greenhouse at this season. The first plant of each tuber unit to reach the stage of anthesis, disregarding the one already inoculated at Stage I, was inoculated at that time, the next one to do so was inoculated 15 days after anthesis (at Stage III), and the last one was inoculated 30 days afterwards (at Stage IV). All were dug at Stage VIII, which was 40 days after the so-called anthesis, or II, 25 days after III, and 10 days after IV. The date of anthesis was not the same for all plants of a tuber unit, differing from 1 to 13 days, the same as for the different tuber units. In Series 8 to 10, inoculation was performed at the same stage of maturity—namely, at anthesis, but the tubers were dug at four different times for each tuber unit. The four plants were harvested, respectively, 10, 20, 30, and 40 days after anthesis, which stages are denoted, respectively, as V, VI, VII, and VIII. The later the date of anthesis the shorter interval of time was allowed between anthesis and harvesting, to make the dates of harvesting as late and as close together as possible. The tubers planted were dug in the field during the last week of July, 1920, and were planted November 15 to 19.

The plants in Series 1 to 10 reached Stage I during the last half of December and Stage II about the middle of January, and were dug up mostly in February. The progeny were planted in the field in May and were observed in August, which was cool, when they showed more distinct mottling than the all-mosaic stocks that were observed in June and July which were warm and dry, at corresponding stages that are usually the best for mosaic diagnosis.

TABLE XIX.—*Inoculations of Green Mountains in the Orono, Me., greenhouse in the winter of 1920–21*

Inoculation.			Inoculated plants.			
			1920–21.		Progeny, 1921	
Series.	Method.	Time.[1]	Hills.	Date dug.[2]	Hills.[3]	Mosaic.
						Per cent.
1	Juice rubbed into mutilated leaves over entire plant (Pl. 13, A).	I	3	VIII	13	0
		II	3	VIII	8	38
		III	3	VIII	12	100
		IV	3	VIII	13	0
2	Juice rubbed into mutilated leaves of lower third of stem.	I	3	VIII	13	0
		II	3	VIII	10	40
		III	3	VIII	11	27
		IV	3	VIII	8	0
3	Juice rubbed into mutilated leaves of upper third of stem.	I	3	VIII	11	0
		II	3	VIII	11	82
		III	3	VIII	9	67
		IV	3	VIII	10	0
4	Stem split in lower part and a portion immersed for several days in a vial full of juice (Pl. 14, A).	I	3	VIII	9	0
		II	3	VIII	10	0
		III	3	VIII	12	0
		IV	3	VIII	12	0
5	Stem split in upper part and a portion immersed for several days in a vial full of juice.	I	3	VIII	12	0
		II	3	VIII	11	0
		III	3	VIII	13	0
		IV	3	VIII	12	0
6	Capillary tubes full of juice inserted in lower part of stem.	I	3	VIII	11	27
		II	3	VIII	13	31
		III	3	VIII	11	0
		IV	3	VIII	10	0
7	Capillary tubes full of juice inserted in upper part of stem (Pl. 13, B).	I	3	VIII	9	0
		II	3	VIII	10	0
		III	3	VIII	10	20
		IV	3	VIII	13	0
8	As for Series 1	II	3	V	9	33
		II	3	VI	11	82
		II	3	VII	10	100
		II	3	VIII	11	91
9	As for Series 2	II	3	V	5	0
		II	3	VI	10	0
		II	3	VII	11	0
		II	3	VIII	6	0
10	As for Series 3	II	3	V	9	33
		II	3	VI	11	73
		II	3	VII	9	67
		II	3	VIII	10	0
SI	Sources of inoculum		6		19	100

[1] Dates of inoculation are designated as I, II, III, and IV, indicating, respectively, the time the plant reached a height of from 10 to 15 cm., the time the first flower-bud cluster was exposed preliminary to the abortive anthesis, the fifteenth day after II, and the thirtieth day after II.
[2] The date of digging was either 10 (V), 20 (VI), 30 (VII), or 40 (VIII) days after II.
[3] Each grown from 1 tuber.

It is seen from Series 4 and 5 of Table XIX that the method in which the stem was split and a part immersed in the juice (Pl. 14, A) was ineffective; from Series 6 and 7, that the inserting of capillary tubes full of juice (Pl. 13, B) was slightly effective; and, from Series 1, 2, 3, 8, 9, and 10, that the leaf-mutilation method was less effective when applied to the lower leaves than when applied to the upper leaves or to all the leaves (Pl. 13, A). With application to the upper leaves or to all (Series 1, 3, 8, 10) the inoculum was most infectious when applied at Stages II or III. The complete ineffectiveness of the stem-immersion method and of the leaf-mutilation method at Stage I, and the comparative ineffectiveness of the capillary-tube method, and of the leaf-mutilation method applied to the lowest leaves (Series 2 and 9), all may be caused by the necessity of introducing the mosaic virus in greater quantity, under certain greenhouse conditions, than was done by these methods. The length of time necessary for infection to reach the tubers is indicated, but will be considered in a later section of this paper.

On December 20, 1920, in the Washington greenhouse, spinach aphids (*Myzus persicae* Sulz.), in the adult stage, were transferred from mosaic potato, variety Bliss Triumph, to caged potato plants, variety Green Mountain, varying in height from 2 to 15 cm. Different numbers of aphids were transferred to 12 series of plants each consisting of four potato plants from a single quartered tuber, so that one untreated control was reserved for three treated plants in each series. A set of six series was treated with aphids numbering 1, 5, or 15 individuals to a plant. The remaining set of six series was treated with aphids numbering 2, 10, or 25 individuals to a plant. When the aphids were transferred but one stalk to a pot was allowed to develop. All the treated plants grew under cages, a separate cage to each pot, during the entire experiment.

Eighteen days after aphids were transferred, examination disclosed that every treated plant was infested in proportion to the number of individuals originally placed upon it; some of the plants treated with 25 aphids showed very decided injury. At this time the aphids were killed with nicotine fumigation. On the plants of the first generation distinct mosaic was observed 27 days after treatment with aphids. With one exception the observations on the second-generation plants confirm those which were made on the vines of the first generation. Data on the vines in the second generation are presented in Table XX.

The results in Table XX indicate that in each of the two groups of tuber units there was more infection as more aphids had been introduced. It is not known why 5 and 15 aphids per plant in the 1-5-15 group produced less infection, respectively, than 2 and 10 aphids in the 2-10-25 group, or why in most of the series the same number of aphids did not always transmit the disease. On the whole, this experiment suggests that a larger number of aphids is more effective in transmitting mild mosaic. These results also suggest that very few aphids sometimes are capable of transmitting the disease.

On December 22, 1921, six Green Mountain plants from 6 to 21 cm. in height were inoculated with juice from a rugose mosaic seedling potato. The inoculated plants were kept in the Washington greenhouse under the same conditions as those inoculated by a single treatment with mild mosaic and without being placed in moist chambers. Also the same strain of Green Mountains was used as in the mild mosaic inoculations (p. 48). By January 19, 1922, there was, on five of the

inoculated plants, a dying of the leaves in spots and streaks which frequently was preceded by slight mottling. On the progeny in the second generation, the mottling and uniform wrinkling was usually more pronounced than in the first generation. Leaf spotting and early death of the lower leaves also obtained in the second generation. The controls in the same tuber units, remained healthy in both generations. Thus another case was added of great contrast between rugose mosaic and mild mosaic.

In the Orono greenhouse during the winter of 1921-22, leaf-mutilation inoculations of four Irish Cobbler hills from two tuber units were made, using inoculum from rugose mosaic Green Mountains. Leaf dropping appeared in all four hills in from 24 to 31 days, but only 7 of the 12 progeny were affected. Parallel inoculations of two Green Mountain hills with inoculum from an Irish Cobbler leaf-roll hill gave negative results in both generations. The results here with two varieties are like those secured in other experiments within either variety.

TABLE XX.—*Effect of variation in the number of aphids upon transmission of mosaic, Washington, D. C., winter of 1920-21*[1]

Series.	Number of aphids introduced.						
	0	1	2	5	10	15	25
31	0:2	....	0:2	....	2:2	....	2:2
32	0:3	....	2:2	....	2:2	....	3:3
33	0:2	....	2:2	....	2:2	....	1:1
34	0:2	....	0:3	....	2:2	....	1:1
35	0:2	0:1	....	2:2	....	0:2	....
37	0:3	0:1	....	0:2	....	1:1	....
38	0:2	0:2	....	0:2	....	0:1	....
39	0:1	1:1	....	0:2	....	2:2	....
40	0:2	0:2	....	0:2	....	1:1	....
41	0:3	....	1:1	....	3:3	....	2:2
42	0:2	0:2	....	1:1	....	0:4	....
43	0:4	....	0:2	....	0:1	....	2:2
Total	0:28	1:9	5:12	3:11	11:12	4:11	11:11
Percentage	0	11	42	27	92	36	100

[1] Progeny of aphid-treated plants given as plants mosaic and total, respectively. Each plant grown from one tuber.

CONCLUSIONS REGARDING INTERVARIETAL TRANSMISSION

The several degeneration diseases described as being diagnosed and transmitted within the Green Mountain variety are also present in other varieties according to the results of intervarietal inoculations. Transmission to Green Mountains from other varieties for ascertaining the identity of the causal virus for various symptom complexes is analogous to the comparison of visible pathogenes from different sources by observing them on the same medium or in the same host. Such comparison indicates that the same virus may induce different symptom complexes in different varieties and that similar symptom complexes in different varieties may be caused by different viruses. Quanjer also points out the value of comparing degeneration diseases in some standard variety

9, p. 130). Some of the differences in diagnosis and terminology may epend upon the use of different standard varieties used in Holland and merica, respectively, for such comparison.

INTERSPECIFIC TRANSMISSION OF MOSAIC INVOLVING POTATOES

The definition of mosaic of potatoes, which apparently includes several istinct diseases, has been given (p. 46) and will serve for mosaic of other pecies of plants. It is not within the scope of this paper to give a review f the extensive literature on interspecific relationships of mosaic. It is ufficient to state here that many species have mosaic, that interspecific ransmission from one taxonomic family to another is unusual in comparion with that within such families, and that the mosaic diseases of various osts, even in the same family, are by no means similar in behavior in egard to seed transmission, infectiousness, viability of the virus, and fficacy of different methods of inoculation. Experiments upon interpecific transmission of mosaic to and from the potato have interest and mportance. They indicate the relationship of potato mosaic to other ypes of mosaic that are better understood and so indicate by analogy he most promising improvements in control measures. They also furish evidence upon the problem of alternate hosts which might serve to erpetuate and spread infection.

The great variation in mosaic behavior indicates that in attempts at nterspecific transmission, the methods used must be selected or modified o suit both species involved. With a given mosaic virus it is desirable o use both a method known to be successful in infecting the usual host and any methods that have been proved effective for a presumably different mosaic virus of the possible alternate host to be tested. In this way the experiment will take into account not only the possibility that the first virus is infectious to the alternate host, but also the possibility that it is infectious only in conditions different from those governing successful inoculation of the normal host.

For example, if needle inoculation alone is used to transmit mosaic from tobacco to potato with observations ceasing in 15 days, it thereby apparently is assumed that the tobacco mosaic virus must act the same in all hosts. On the other hand, if it is deemed possible either that the tobacco virus may be responded to differently in the potato, or even that both mosaics are caused by the same virus with different behavior in different hosts, it is desirable to use methods that are reliable for both mosaics in the respective normal hosts. Another example is a needle inoculation of cucumbers with juice from mosaic potatoes, with observations ending in 13 days. This method may test sufficiently the possibility of the potato mosaic virus being the same as the cucumber mosaic virus, but it would ignore the possibility that the potato virus could be transmitted to cucumbers in the same conditions needed for successful inoculation within the normal host, the potato. Whenever interspecific transmission between two hosts is demonstrated it is still necessary to make further comparisons in regard to symptoms, susceptibility of hosts, ease of inoculation, and incubation period, in order to determine as nearly as possible whether one or more viruses are involved.

POTATOES AND OTHER MEMBERS OF THE SOLANACEAE

In view of the requirements stated above, no completely adequate test has been reported showing that interspecific transmission between pota-

toes and any other members of the Solanaceae is impossible, except the earlier grafting experiments of Quanjer (*38, p. 42*) with tobacco and potato. Transmission of mosaic from tomato to potato and from tomato to tobacco, and the reverse of each, has been reported by Quanjer (*38, p. 42*). Here it seems possible either that a virus was involved, different from that of tobacco mosaic and those of potato mosaic in being infectious to all three hosts, or that the tomatoes were affected only with a combination of tobacco mosaic and potato mosaic. Later, Quanjer has reported transmission of common mosaic by grafting, from potato back to tomato and to tobacco (*39, p. 134*):

> True infectious mosaic ...... can be transmitted by grafting to other solanaceous plants, e. g., tomato and tobacco.

The details of his evidence are not given. Transmission of mosaic from a perennial weed, *Physalis longifolia* Nutt., to potatoes has been reported by Melhus (*27*). Quanjer has indicated the communicability of several degeneration diseases of potatoes to a considerable number of species of the Solanaceae (*39, p. 132, 134, 136*). The experiments to be reported here are with tobacco (*Nicotiana tabacum* L.), tomato (*Lycopersicum esculentum* Mill.), and common nightshade (*Solanum nigrum* L.).

POTATO, TOBACCO, AND TOMATO

Tobacco mosaic can be transmitted readily by means of a needle or by contact which breaks the trichomes (*3, p. 615–17*). The incubation period may be only 5 days (*3, p. 615*) and usually is no longer than 12 to 15 days (*2, p. 17*). Potato mosaic of the most virulent type has not been transmitted by inoculations approaching the needle method in mildness, and has a minimum incubation period of 12 days. With mild mosaic of potatoes unless inoculation is performed early and the growing period of the potato vines is lengthened by growing them either in a field insect cage or in the greenhouse, any infection that occurs will not assuredly be apparent during the first generation. Either tobacco mosaic is caused by a more virulent contagium than any potato mosaic yet described, or, if its cause is identical with that of a potato mosaic, the symptoms are greatly modified by potatoes.

Experiments performed in the Orono greenhouse in the winter of 1919–20 are described in Table XXI. The tobacco plants grew from Connecticut Broadleaf seed, and mosaic was introduced both from dried mosaic tobacco leaves collected by Dr. W. J. Morse in Connecticut and from living mosaic tobacco plants sent from the greenhouse at Washington, D. C. The potato plants were of the Green Mountain variety and came from northeastern Maine.

The data in Table XXI show that methods of inoculation adequate to transmit tobacco mosaic or potato mild mosaic within the species effected no apparent interspecific transmission. Leaf-mutilation juice transfer transmitted mosaic from diseased to healthy potato (Series and 13) and from diseased to healthy tobacco (Series 6) as shown in Plate 15, B, but not from diseased potato to healthy tobacco (Series and 12) or from diseased tobacco to healthy potato (Series 5 and 14). Spinach aphids transmitted mosaic from diseased to healthy potato (Series 4 and 8), but not from diseased potato to healthy tobacco (Series 3) or from diseased tobacco to healthy potato (Series 7). The aphid colonies did not thrive on tobacco sufficiently for control aphid inoculations (diseased to healthy tobacco) to be made but Allard (*3, p. 626–2*

und this species to be a transmitting agent. It will be noted (Series 9) at aphids from potato inoculated with tobacco mosaic were noninfectious, indicating that potato was not a susceptible masking host or mptomless carrier. Aphid colonies did not establish themselves on e tobacco plants inoculated with potato mosaic, for a corresponding st of tobacco as a symptomless carrier of potato mosaic. A number of ntrol inoculations from healthy plants of one species to the same in the her were made, but are of no significance in view of the negative results om mosaic inoculations.

ABLE XXI.—*Mosaic inoculations between potato and tobacco (Orono, Me., winter of 1919–20)*

Series.	Source of inoculum.	Method of inoculation.	Inoculated plants.
1	Mosaic potato......	Juice stabbed in Feb. 28; leaf mutilation Mar. 9, 15, and 24.	Five, tobacco, largest leaf 10 cm. long Feb. 28. Healthy Apr. 26.
2	...do..............	Leaf mutilation Mar. 6–9, 15, and 24.	Two, potato, 2 cm. tall Mar. 6–9. Healthy Apr. 26. Second generation, 8 of 9 tuber units mosaic.
3	...do..............	Spinach aphids, 25 to 100 to a plant, Feb. 5 or 17. Fumigated 5 to 7 days later.	Ten, tobacco, with 3 to 6 leaves over 1 cm. long when inoculated. Healthy Mar. 26.
4	...do..............	Spinach aphids, 60 to 200 to a plant, Jan. 16 or Feb. 3.	Two, potato, 8 cm. tall when inoculated. Mosaic in 29 to 32 days. Second generation mosaic.
5	Mosaic tobacco....	Leaf mutilation Mar. 5–9, 16, and 24.	Four, potato, 2 cm. tall Mar. 5–9. Healthy Apr. 26. Second generation healthy.
6	...do..............	Leaf mutilation Feb. 16.	Five, tobacco, with 6 or 7 leaves over 1 cm. long when inoculated. Mosaic Mar. 2 and possibly before (Pl. 15, B).
7	do..............	Spinach aphids, 10 to 80 to a half-tuber, Apr. 14. Fumigated Apr. 21.	Eight, potato half-tubers, with sprouts 2 to 5 mm. long. Plants healthy.
8	Mosaic potato......	Spinach aphids, 25 to 100 to a half-tuber, Apr. 14. Fumigated Apr. 21.	Seven, potato half-tubers, with sprouts 2 to 5 mm. long; 4 of the 7 plants mosaic by June 26, and 5 by July 21.
9	Inoculated potato, of Series 5.	Spinach aphids Apr. 3...	Tobacco, with leaves not over 2 cm. long. Healthy Apr. 26.
10	None..............	None..................	Control parts of tuber units of Series 2, 4, 5, 7, and 8 healthy. Second generation of Series 2, 4, and 5 also healthy.
11	....do............	....do.................	Control tobacco, healthy Apr. 2. (See Series 6.)
12	As for Series 1.....	Leaf mutilation once....	Tobacco, healthy (Pl. 15, B).
13	As for Series 2........	... do..................	Potato. Healthy in first generation. Mosaic in 8 per cent of the second.
14	As for Series 5..........	...do..................	Potato, healthy.
15	Mosaic potato......	Growth in soil recently occupied by diseased plant.	Many seedlings in 5 pots, healthy 6 weeks after germination.

During the winter of 1919–20 in the greenhouse at Washington, D. C., cross inoculations by leaf mutilation with mosaic between potato, tobacco, and tomato indicated that the tomato was susceptible to potato mosaic, that the tobacco was susceptible to tomato mosaic but not to potato mosaic, and that the potato was not susceptible to tobacco mosaic. These reactions suggested that the tomato either responded symptomatically to two different mosaic diseases or served as a necessary intermediate host for one mosaic between potato and tobacco and vice versa. Accordingly, in the winter of 1921–22 additional cross inoculations between these hosts were made. In addition, cross inoculations with different types of potato mosaic were performed largely between potato and tomato in order to observe the reaction of the tomato to these diseases. The varieties used are indicated in Table XXII. Potato and tobacco plants at the time of inoculation varied in height from 8 to 1[illegible] cm. and the tomato plants from 15 to 30 cm. Inoculations in each case were made by leaf mutilation. A single inoculation was made with the exception of Series 15, which received four applications at weekly intervals. Inoculated and control plants came from seed pieces from the same tuber in the potato, and in the tomato cuttings and seedlings from the same lot. Inoculated plants and their controls grew in the same greenhouse, which was fumigated regularly for the control of aphids and white fly (*Aleyrodes vaporariorum* Westw.). The controls remained free from mosaic.

The results shown in Table XXII indicate that the tomato is susceptible to tobacco and potato mosaic and that the symptoms vary between tobacco and potato mosaic, being filiform in part as a result of mosaic of tobacco, and mild mosaic or simply mottling, ruffling, and wrinkling as a result of infection with mild mosaic of potato.

Furthermore, the tomato reacted differently to the different types of degeneration diseases represented in the potato, being mild mosaic after inoculation with potato mild mosaic, and rugose mosaic with either rugose mosaic or with streaking plus mottling of potato. Tomato in Series [illegible] showed the mottling of potato mosaic more readily than the potato itself; mosaic mottling in this case appeared in 12 days, while the potato had failed to show mottling at the end of 27 days.

A comparison of Series 1, 3, and 15 discloses an apparent difference between potato mosaic and tobacco mosaic and suggests the harboring of two distinct mosaic diseases by the tomato. The mosaic tomato in Series 3 became infected from some unknown source, presumably by the potato mosaic in a separate greenhouse during the summer, while the tomato in Series 15 was inoculated with tobacco mosaic, which was not transmitted to the potato in spite of four repeated treatments, as the first and also second generation plants indicated.

TABLE XXII. *Interspecific inoculations with mild mosaic, rugose mosaic* [illegible]

Inoculation series.	Date of inoculation.	Source of inoculum. Plant.[1]	Source of inoculum. Symptoms.	Inoculated plants. Plant.	Inoculated plants. Number.	Inoculated plants. Number infected.	Inoculated plants. Symptoms.
	1921.						
1	Dec. 13	Tobacco (Connecticut Broadleaf).	Mosaic	Tomato (Norduke)	12	12	Filiform leaves followed by mottling on leaves formed later.
			Mild mosaic	...do	16	16	Mild mosaic.
2	Dec. 16	Green Mountain	Mosaic	Green Mountain	6	3	No mosaic in first generation; mild mosaic in second generation.
3	Dec. 20	Tomato (Norduke)					
4	Dec. 22	Seedling 40552	Rugose mosaic	Tomato (Norduke)	5	5	Rugose mosaic.
5	Dec. 24	Seedling 13858	Streak	...do	5	5	Wrinkling and ruffling of leaves.
	1922.						
6	Jan. 4	Green Mountain	Rugose mosaic	...do	3	3	Rugose mosaic.
9	Jan. 11	Seedling 41034	Necrotic spotting on leaves	...do	4	4	Do.
10	Jan. 16	Green Mountain	No mosaic mottling, although inoculated 30 days ago with mild mosaic juice from Green Mountain. Showed mild mosaic later.	...do	5	5	Mild mosaic.
11	Jan. 19	Seedling 41069	Streak and mottling	...do	4	4	Rugose mosaic.
14	Jan. 27	Green Mountain	Mild mosaic	...do	8	8	Mild mosaic.
[2] 15	Jan. 31	Tomato (Norduke)	Filiform leaves and mottling (inoculated with mosaic tobacco).	Green Mountain	9	0	No mosaic in first or second generation.

[1] Potato, unless otherwise stated.

[2] Four inoculations at weekly intervals.

POTATO AND NIGHTSHADE

Seed from a volunteer plant of common nightshade was planted in steam-sterilized soil in the greenhouse at Orono in the winter of 1919-20. The seedlings were transferred to similar soil in small pots and grouped in five series, as follows.

Series 1

Spinach aphids were transferred from mild mosaic Green Mountain potato plants to 13 caged nightshade plants growing in nine pots and were killed a week later by fumigation. The results, together with other data, are given in Table XXIII. Table XXIII shows that 2 of the nightshade plants were certainly mosaic in appearance and 7 others could be placed almost in the same class (Pl. 15, D). The only plants that showed no mosaic symptoms were 3 that were smaller, when the aphids were introduced, than others in the same pots. Probably they were not fed upon by the aphids. The first mosaic symptom, leaf curling, appeared in from 20 to 47 days after inoculation.

TABLE XXIII.—*Transference of aphids from mosaic potato plants to healthy nightshade plants*

Pot No.	Aphids introduced. Number.[1]	Aphids introduced. Date.	Number of leaves on plant.[2]	Date of appearance of mosaic symptoms. Leaf curl.	Leaf collapse.	Wrinkling.	Complete.
1	70	Feb. 17	7	Mar. 16	Mar. 25	Mar. 31	Apr. 6.
			2	None.....	None.....	None.....	
2	40	...do.....	6	Mar. 16	...do.....	...do.....	
3	50	...do.....	7	...do.....	Mar. 25	Mar. 31	Not Apr. 26.[3]
4	60	Feb. 24	9	...do.....	...do.....	Apr. 6	Do.
5	95	...do.....	8	Mar. 31	Mar. 31	Mar. 31	Apr. 12.
6	80	...do.....	7	Apr. 6	None.....	Apr. 6	Not Apr. 26.[3]
			4	None.....	...do.....	None.....	
			2	...do.....	...do.....	...do.....	
7	50	...do.....	8	Mar. 25	Mar. 25	Mar. 31	Do.[3]
8	80	...do.....	7	Mar. 16	Mar. 31	Apr. 6	Do.[3]
9	80	...do.....	7	Mar. 25	Mar. 25	...do.....	Do.[3]
			5	Apr. 12	None.....	Apr. 12	Do.[3]

[1] Approximate.
[2] Over 1 cm. in length, including the cotyledons.
[3] Probably mosaic, however, even though not completely so.

Series 2

Healthy controls to Series 1, with each of five plants in a separate pot, were fed upon for a week by 40 to 100 aphids. The aphids were introduced on March 8 when there were eight or nine leaves each over 1 cm. in length. No mosaic symptoms had appeared on April 26, when all plants were discarded, in marked contrast to those of Series 1 growing alongside (Pl. 15, D).

Series 3

On February 9, 1920, juice expressed from mild mosaic potato plants was inoculated into the mutilated leaves of 10 nightshade plants when the number of leaves over 1 cm. long was from three to eight. Only

aves of this length were inoculated, and these were so thin they could ot be bruised as much as is necessary for the successful inoculation of otatoes. They were somewhat mutilated with the finger nails and y pinching, with juice present on the fingers and applied after mutilation. ne of this series became mosaic (Pl. 15, D).

Series 4

Healthy controls to Series 3, with each of five plants in as many pots, ere inoculated similarly with juice from healthy potato plants. No osaic symptoms appeared by April 26.

Series 5

Three untreated controls were transplanted and 13 were not. All emained healthy throughout the experiment.

The five preceding series indicate that potato mild mosaic virus is nfectious to a high degree when introduced by aphids, and to a slight xtent when introduced by leaf mutilation, to nightshade. Return noculations from mosaic nightshade plants to potatoes were made to prouted tubers in the same manner as in the tobacco-potato Series 7 nd 8 of Table XXI. It will be remembered that in the control Series , aphids from mosaic potato plants infected 71 per cent of the half-ubers. The 29 per cent of Series 8 that remained healthy were fed upon by fewer aphids than the rest of the series, only 30 being introduced o a half tuber. Two series were involved with nightshade and sprouted otato tubers, as described in the following paragraph.

Series 6

Spinach aphids on mosaic nightshade plants were not very numerous. Those present were on the plant of pot 8, Table XXIII, under a cage, and were established there on April 6 as a proved nonvirulent colony from radish plants. Fifteen or 20 were transferred to each of five sprouted half-tubers and 20 per cent of the half-tubers became mosaic. Thus mosaic was transmitted from nightshade to potato tubers by fewer aphids than were required to transmit it from mosaic potato vines.

Series 7

Healthy controls to Series 6 were fed upon by aphids from healthy nightshade plants, which produced no infection.

Series 6 and 7 indicate that if enough aphids are transferred to potato from mosaic nightshade, infected from potato, there will be as much infection as when they are transferred from mosaic potato.

The experiments with nightshade and tobacco were performed in the same greenhouse but in different rooms. Since tobacco mosaic can be transmitted to nightshade (*2, p. 10*) it was slightly possible that the mosaic nightshade plants had become infected in some way from mosaic tobacco. Therefore spinach aphids were transferred from a mosaic nightshade plant to small tobacco seedlings, on April 6. The aphids fed and increased until April 26, but all the tobacco seedlings remained healthy.

POTATOES AND PLANTS IN DIFFERENT FAMILIES

Transmission of mosaic from cucumbers (*Cucumis sativus* L.) to po-
toes has been reported by Doolittle and Walker (*11*). The mosaic
cucurbits seems to be the most virulent type known and to be the
most easily transmitted from one family of hosts to another. Howe
as in northeastern Maine, where potato mosaic is common, the wri
have not yet found any wild members of the Solanaceae, it has
necessary to consider the possibility of transmission of potato mo
between families in connection with the problem of perpetuation
weeds. In this region the writers have observed mosaic in garden be
(*Phaseolus vulgaris* L.), evidently introduced in the seed. A very co
mon mosaic is that of the numerous wild red raspberries (*Rubus*
A mosaiclike disease is sometimes common on certain composites
resembles one type of aster yellows. The raspberry mosaic is the
one of these diseases that has been tested by the writers in regard
transmissibility to potatoes.

POTATO AND RASPBERRY

In the Orono greenhouse in the winter of 1920–21, cultivated mo
raspberry bushes were transplanted in October and grown until
period of dormancy was passed. On January 28, the new shoots w
ground up and juice obtained consisting of distilled water and w
could be washed and squeezed out of the rather dry pulp into the wa
The juice was used in leaf-mutilation and capillary-tube inoculat
corresponding to those described in Table XIX, where potato mo
was transmitted. Each method was used in four hills taken, respectiv
from four 4-hill tuber units. The 16 plants in these tuber units w
all healthy, as were also the 50 plants of the second generation. T
indicates that two methods of inoculation that transmitted mosaic fr
potato to potato, were not effective in transmitting mosaic from rasph
to potato. No aphids abundant in northeastern Maine are known
infest both Rubus and potato (*37*), which might explain why proxim
of healthy potatoes to mosaic raspberry has caused no apparent infecti

CONTROL OF DEGENERATION DISEASES OF POTATOES

The desirability of controlling any one or more of the degenerat
diseases depends upon the effect on the yield rate and on the quali
The determination of such effects requires correct diagnosis of the dis
or diseases involved. With a given disease, distinction should be ma
between hills or plots with current-season infection (usually no sympto
with second-season infection (usually first-season symptoms) and w
third-season infection (Pl. 14, B). Until it is clearly shown that diseas
free strains (stocks of the same variety recently secured from differe
sources) have no inherent differences that survive growth and the produ
tion of seed in the same environment, it is also desirable to compa
effects of a disease in parts of the same strain. It may be readily se
that it is difficult to secure an extensive comparison fulfilling the pre
ceding requirements and giving due consideration to soil, variety, an
climate or season, especially when infectious diseases are present t
contaminate the healthy parts of strains. Further, the total percenta
of incidence may affect the average reduction of yield rate by each pe
cent of diseased hills, and diseases in combination may have an effe

ater or less than the sum of the effects of both considered separately. h a given yield rate, the quality may be affected with a loss depending ewhat on the demands of the trade regarding the characteristics of tubers or progeny.

ADVANTAGES TO BE DERIVED FROM CONTROL

Table XXIV summarizes the results of a number of yield tests that ve been made with parts of the same strain in each of two varieties. L strains secured on the L farm will be discussed first. In 1918, on oostook Farm, the yield rates were reduced by an all-mosaic condition ild type) slightly more for Bliss Triumphs than for Green Mountains comparison with plots with part of the hills—the mosaic ones— moved during the season. In 1919, on Aroostook Farm, the yield rates re reduced by an all-mosaic condition much more for Bliss Triumphs an for Green Mountains, in comparison with plots with about a fifth the hills mosaic. In 1920, on a field with poor soil and cultural condins, the yield rates were reduced less by an all-mosaic condition for iss Triumphs than for Green Mountains, in comparison with plots with out a fifth of the hills mosaic. In 1919, the only year of the three in ich conditions were at all normal and favorable for growing potatoes d for making such a test, for each 10 per cent of mosaic the reduction ounted to 2.8 barrels [4] an acre for Green Mountains and to 5 barrels for iss Triumphs.

In these two strains and in many small lots (*40, p. 316*) the writers ve not observed an increase in severity in symptoms except in some ses where another disease, such as the spindling-tuber disease, came in increased, as in the following tests. In 1921, on Aroostook Farm, the me Green Mountain stock mentioned above was again used for yield sts. One part about a third mild mosaic and a third spindling tuber, th first-year symptoms following infection late in 1920, had a yield te of 146 barrels an acre. A part all mild mosaic, as for several years least, and about a third spindling tuber (first-year symptoms) had a eld rate of 96 barrels. Another part all mild mosaic, as for several ars, and all spindling tuber with the second-year symptoms (third year disease) had a yield rate of 68 barrels.

Comparing the first and second parts gives a reduction of about 7 arrels an acre for each 10 per cent of mild mosaic, while comparing the cond and third parts gives a reduction of about 4 barrels an acre for ch 10 per cent of spindling-tuber disease in mild mosaic stock. In ese tests the size of the plots varied from one-fifth to one-fourth of an re in 1918 and 1919, from one-ninth to one-fifth in 1920, and from oneeventh to one-sixteenth in 1921.

Further comparisons in Table XXIV lead to the following conclusions: he mosaic part of a strain sometimes yielded less than a partly rogued ealthy part, as in Green Mountain strain L (1918, 1920), in Bliss Triumph rain L (1918, 1919, and 1920), and in Green Mountain strain S (1920). he mosaic part of a strain sometimes yielded more than a rogued healthy rt but only so if the allowance is not made for loss by roguing, as in reen Mountain strain L (1919), strain S (1918 and 1919), and strain W. he mosaic part of a strain sometimes yielded less than an unrogued ealthy part, as in Green Mountain strain L (1919; 1920 on P farm;

[4] A "barrel" (barrelful) is 165 pounds, or 2¾ bushels.

1920 on Long Island; 1921), Bliss Triumph strain L (1919; 1920 [illegible] farm), and Bliss Triumph strain R. In one case (Green Moun[illegible] strain C) a slightly mosaic part yielded a little better than a no-mo[illegible] part. The spindling-tuber disease decreased the yield rate where pre[illegible] in Green Mountain strain L (1920 and 1921). In this strain growth [illegible] Long Island was accompanied by a greater reduction in yield rate [illegible] mosaic than on P farm.

TABLE XXIV.—*Yield tests on effect of mild mosaic and spindling-tuber disea[illegible] strains*

Strain.[1]	Year.	Part.	Area.[2]	Yield rate. Barrels per acre.	Yield rate. Per[illegible]
			Acre.		
Green Mountain L.	1918	Rogued of 11 per cent mosaic	1/5	89	
		All mosaic	1/4	69	
	1919	Rogued of 20 per cent mosaic	1/4	[3] 104 (130)	
		20 per cent mosaic	1/5	144	
		All mosaic	1/5	122	
	1920	Rogued of 15 per cent mosaic	1/10	....	
		Rogued of 21 per cent mosaic	1/10	....	
		21 per cent mosaic, on P farm	1/6	83	
		50 per cent mosaic	1/10	....	
		12 per cent mosaic, all spindling tuber.	1/30	....	
		All mosaic on P farm	1/5	65	
		16 per cent mosaic on Long Island.	1/11	....	
		All mosaic on Long Island	1/15	....	
	1921	36 per cent mosaic and about 30 per cent spindling tuber.	1/5	146	
		All mosaic and about 30 per cent spindling tuber.	1/16	96	
		All mosaic and all spindling tuber.	1/8	68	
Bliss Triumph L.	1918	Rogued of 15 per cent mosaic	1/5	75	
		All mosaic	1/5	53	
	1919	Rogued of 20 per cent mosaic	1/4	84	
		20 per cent mosaic	1/5	100	
		All mosaic	1/5	60	
	1920	Rogued of 26 per cent mosaic	1/10	....	
		44 per cent mosaic	1/10	....	
		21 per cent mosaic on P farm	1/5	84	
		All mosaic on P farm	1/9	82	
Green Mountain S.	1918	Rogued of 13 per cent mosaic	1/4	[3] 84 (97)	
		45 per cent mosaic	1/2	86	
	1919	Rogued of 30 per cent mosaic	1/4	[3] 112 (160)	
		68 per cent mosaic	1/4	133	
	1920	Rogued of 22 per cent mosaic	1/10	....	
		89 per cent mosaic	1/10	....	
Green Mountain W.	1919	Rogued of 32 per cent mosaic	1/4	[3] 106 (156)	
		30 per cent mosaic	1/4	147	
Green Mountain C.	1920	0.2 per cent mosaic	1/10	....	
		6 per cent mosaic	1/10	....	
Bliss Triumph R.	1920	Rogued of 2 per cent mosaic	1/10	....	
		7 per cent mosaic	1/10	....	

[1] Each strain was divided in the year previous to the first given here, by hill selection or by part [illegible] rogued.

[2] Area given is approximate and on Aroostook Farm unless otherwise stated.

[3] Yield rate in parentheses is that calculated for 100 per cent assuming the rogued percentage to have [illegible] a directly proportional loss.

Mosaic is well distributed over the United States (*45, p. 248; 14, p.*), having been reported in 1917 and 1918, from 21 States, including those in which potatoes are an important crop. The existence of eral types and the modification of symptoms by varietal and environmental factors make it probable that the true extent and meaning of geographical distribution of mosaic is merely beginning to be fully lized. Sixty-eight strains of Green Mountains from seed grown in nada, Maine, New York, Vermont, and Wisconsin, were tested in place and found to have an average of 33 per cent mosaic (*1, p. 11*) d as high as 48 per cent (*35, p. 8*). Mosaic was common in seed-tato fields of Maine and northern New York in 1915 (*46, p. 357*). e average mosaic percentage for Green Mountains in New York and ostook County, Me., is given by Barrus (*6, p. 13*) as 50 per cent or re, with 20 per cent or less as rare. During 1919, the writers made a reful estimate of the amount of mosaic in 40 Green Mountain fields d the same number of Bliss Triumph fields in northeastern Maine. any of these were supposed to be above the average in freedom from e disease. Mosaic varied from one-half per cent to 100 per cent, eraging 28 for the Mountains and 46 for the Bliss. Similar results lowed the examination of fewer fields of these varieties in 1920, and supposedly choice American Giant fields were found to contain m 3 to 46 per cent, averaging 13. In Green Mountains in *1921*, 26 lds in northeastern Maine averaged 32 per cent, and 58 fields in New unswick, mostly in the northern part, averaged 13 per cent mosaic. st of the mosaic in commercial fields in northeastern Maine and New unswick is of the mild type. Variation in Louisiana from 3 to 90 per nt in Bliss Triumps is reported (*12, p. 8*), with losses as high as total ilure (*12, p. 3*).

The reduction of yield rate by leaf roll has not been determined in ots. Leaf roll does not extend so far north as a prevalent disease as es mosaic. Both are prevalent in western New York and southern ntario (*29, p. 36*), while in northern Ontario mosaic is troublesome but af roll is not (*28, p. 5*). The writers have found leaf roll much less mmon than mosaic in northeastern Maine in varieties badly affected sewhere with both (*41, p. 75*). When leaf roll causes net necrosis in e tubers, the quality of the crop is affected as well as the yield.

Leaf-rolling mosaic alone appears to affect the plants about as mild osaic does, but in combination with spindling-tuber disease (giving form of curly dwarf in Green Mountains as least) the yield rate is considerably reduced (*46*).

The spindling-tuber disease seems to reduce the yield rate less by the rst year symptoms (in plants growing from normal shaped tubers roduced by plants infected late in the season) than by the second-ear symptoms (in plants growing from spindling tubers) (Pl. 14, B). t is present in all percentages of incidence in several varieties in orthеastern Maine. Its presence in at least 10 widely separated States s known from personal observations by the writers and from personal nd written reports by pathologists. Its production of abnormally haped tubers injures the quality of the crop for sale as seed and table tock.

Rugose mosaic, streak, and unmottled curly dwarf are each more njurious to the yield rate than the four diseases just mentioned. They, nd also leaf-rolling mosaic and spindling-tuber disease, are probably

more generally distributed over the potato-growing regions tha shown by reports now available.

Lack of control of these various degeneration diseases causes l to seed buyers because of their appearance in plants grown from parently normal and healthy tubers. This reacts on the sellers of Control therefore will not only improve the yield of generally sa tubers, but will also improve the quality of the crop for seed purp

GENERAL FACTORS INVOLVED IN CONTROL

TRANSMISSION

From the results of the experiments described in preceding par this paper, it may be concluded that by aphids and possibly ot means there is danger of degeneration diseases spreading in the from diseased to healthy hills or from diseased to healthy fields. stock of Norcross (Green Mountain group) grown in a large field Aroostook Farm had 55, 80, 95, 99, and 100 per cent of the hills mosaic, respectively, in the five years from 1918 to 1922. Other sto of smaller size have here shown a similar steady increase of mild mo and of spindling-tuber disease, but not of leaf roll. That such freque annual increase in the percentage of incidence is due to infection healthy hills from the diseased ones in the same field is shown by cert hill selections, to be described in a later section of this paper. Al the effect of different degrees of isolation of healthy stocks from disea stocks will be shown in a later part of this paper. The removal diseased hills serving as sources of infection, and the control of inse that transmit these diseases, are important phases of control to given attention later.

If any experiment should eventually indicate that transmiss through the soil is possible, it will be necessary to test or elimina various soil factors (such as subterranean insects, soil water, soil ma or débris from diseased plants) in order to determine the exact meth of transmission. At present neither soil nor root-contact transmiss has been demonstrated.

PERPETUATION

The question of perpetuation in diseased weeds has been considered connection with interspecific transmission. It seems to be of importan in some regions and not in others.

The possibility of perpetuation in the soil exclusive of diseased tub has been tested in pots, with negative results in both the first and secon generations (*40, p. 335*). This experiment involved contact with som of the roots of plants recently removed. Field experiments also gav negative results with mosaic, both in the first (*40, p. 335–36*) and secon generations, and whether begun upon the ground of 1918 plots or of 191 plots. In the latter (Table XXVII, field D) dead mosaic vines wer buried in the furrow at planting time. The same negative result resulted from tests with leaf roll reported by the writers (*41, p. 59*) by Quanjer (*38, p. 41–42*), Wortley (*50*), and Murphy (*29, p. 52–53*) and from tests with mosaic dwarf by Krantz and Bisby (*21, p. 15–18*).

The well-known perpetuation through the tubers is of great importance It requires the avoidance of fields containing viable overwintering dis eased tubers such as were present in northeastern Maine in the spring o 1919 (*40, p. 335*) and of 1921 (Pl. 14, C).

t makes it desirable to inspect the fields that produce the seed tubers, e the condition of the parent plants has more effect on the progeny n the conditions of seed-tuber storage or of the growth of the progeny. er phases of tuber perpetuation will be discussed in connection with question of tuber selection.

DIFFUSION OF THE CONTAGIUM

The spread of the contagium or virus within the plant will be termed iffusion." Stocks assuredly mosaic, that have shown the symptoms mild mosaic for several seasons, usually do not show the symptoms the first part of the season (several days to several weeks) and often e them in the last part. This seasonal cycle is considered by the iters to be the result not of diffusion of the contagium to and from the aves, but rather of the effect of the degree of maturity upon leaves coning the virus, and frequently shows variations due to temperature d other environmental factors. Diffusion of the virus from the point inoculation in the vines to the tubers may occur without the appearce of symptoms, even after the normal period of incubation, if the leaves ve ceased growing. The time needed for this diffusion is of importance relation to the possibility of tuber infection being reduced by an early ath of the aerial parts of the plants, after the latter have been inocuted by insects.

Knowledge of virus diffusion may explain the disease division of hill ts, tuber units, hills, and shoots, where the progeny of a hill or of a ber, and even a single shoot, may be only partly diseased. Although ch disease division may be caused by recent insect inoculation in some ses at least, it occurs in conditions where such insect inoculation is not satisfactory explanation. Incompleteness of diffusion is of interest to hose who test hills or tubers by sampling one eye of each, and to those ho plant a seed plot by tuber units. If its occurrence in a seed tuber s sometimes the cause of the late appearance of symptoms in the upper part of the plant, it is also important to those who attempt to remove all diseased hills early in the season.

In the winter of 1920–21, at Orono, the plants of nine tuber units were noculated at different times by the leaf-mutilation method with inoculum rom mild-mosaic Bliss Triumph plants, and were dug within a certain eriod of time after inoculation. Three different intervals elapsed for arts of each tuber unit. The progeny were grown in the field in 1921, nd showed symptoms as described in Table XXV, for Series 1. In nother series (No. 2 of Table XXV) the plants of three tuber units were noculated with a reliable method similarly at a given time and four diferent intervals elapsed for parts of each tuber unit. In each series, 0 days allowed much less diffusion of the virus to the tubers than 20 lays or longer. This helps to explain why digging seed tubers within 0 days after the maximum infestation by transmitting insects avoided he maximum amount of disease (p. 104). It also indicates how early utumnal killing frosts in northern regions, following the usual late spring atching of aphid eggs and consequent late development of infestation, night contribute to the general less abundance of degeneration diseases n the north, resulting in the well-known preference for northern-grown eed (*10, p. 162–63*).

TABLE XXV.—*Effect of difference in time elapsed between leaf-mutilation inoculation with mild mosaic and removal of tubers*

Tuber-unit series.	Inoculation period.	Date of tuber removal (number of days after inoculation).	Progeny mosaic.[1]	
			Number inoculated.	Mosaic.
				Per cent.
[2] 1	Exposure of first flower-bud cluster	40	29	[illegible]
	Fifteenth day after bud exposure	25	32	[illegible]
	Thirtieth day after bud exposure	10	31	[illegible]
[3] 2	Exposure of first flower-bud cluster	10	9	[illegible]
		20	11	[illegible]
		30	10	[illegible]
		40	11	[illegible]

[1] 1 hill from each tuber.
[2] Series 1, 2, and 3 of Table XIX, excluding plants inoculated before anthesis.
[3] Series 8 of Table XIX.

It has been reported (*40, p. 318*) that a small proportion of tuber units may contain both healthy and mosaic hills, and that in such mixed tuber units the diseased hills are at first about evenly distributed between bud-end hills and stem-end hills but later are more common in the bud-end hills. The difference thus shown at first between sister hills in regard to mosaic is apparently due either to unequal retardation of the appearance of symptoms or to unequal distribution of the virus in the tuber. The later development of the difference between bud-end and stem-end hills may be due, as far as is known, to the greater number of eyes in the bud-end quarters and the resulting better chance to include a diseased eye, or to field infection that affects the faster-growing bud-end plants more and that produce symptoms apparent the same season.

In some cases of possible early field infection with current-season symptoms, at first only part of a hill or stalk is diseased—either one branch or the upper leaves or even one side of a branch, and the infection then spreads to the new growth, whereas perpetuation by tubers from diseased hills is followed by uniformly distributed symptoms. This partial infection appears later than that which evidently follows tuber perpetuation, being in 1921 about the only type found after the second roguing in a rogued and isolated seed plot that contained aphids earlier in the season. It is correlated with the presence in the field of virus diseases especially of the more injurious and virulent types, being more abundant in the experimental plots than in commercial fields, where it is found infrequently. Furthermore, it is found, in experimental plots, indiscriminately in partly diseased lots, in lots from stock that came from healthy fields and that are healthy in commercial fields, and in lots with the preceding generation grown under cages or in greenhouses with no opportunity or evidence of infection occurring. Murphy has noted such partial display of current-season symptoms (*29, p. 62-63*).

In 1920, several thousand Green Mountain tubers from many sources, mostly experimental plots, were split in two and planted as 2-hill tuber units. Thirty-seven tuber units either were partly mosaic—that is, with one or more stalks partly or wholly healthy, in the first week of July (when progeny of all-mosaic lots planted in the same field in the same

ay were all diseased)—or were healthy then and partly mosaic later. In these 37 tuber units, often different stalks in a hill were affected with different severity. Whether healthy or partly mosaic on July 1, these units became more diseased as the month progressed. They could be arranged in a series of gradually increasing amount and severity of disease. They seemed to be either the last hills to show mosaic as the result of 1919 infection or hills that showed the first symptoms resulting from 1920 infection. If the last to show 1919 infection, they would seem to be so because of incompleteness of infection of the tubers in 1919. If they were mosaic as the result of 1920 field infection, the identity of the transmitting agents is in doubt, since aphids were not discovered on June 26. On July 26 they were limited to colonies each of about a dozen consisting of a mature potato aphid individual and her young ones. A shoot in the Orono greenhouse, where aphids were absent, was observed having one side mosaic, the line of distinction between diseased and healthy even bisecting two leaves lengthwise.

Whatever the cause of delayed and partial manifestation of symptoms, the effects are troublesome. About a fourth of these 37 tuber units became affected with streaking between July 1 and 26. This streaking was either accompanied or preceded shortly by the appearance of brittleness and mottling. A few more became thus affected between July 25 and August 27, one alone with no mosaic mottling. This single apparent exception to the rule of association of mottling and streaking was not surprising since mottling had become reduced in distinctness or entirely effaced in over one-third of the tuber units. Thus, in certain tuber units streaking was an accompaniment of mottling that appeared later than normal and that was found in only part of each unit. Moreover, in many of these units mottling became reduced during August even though the variety was Green Mountain, one that retains this symptom better than most varieties, and the streaking was followed in part by progressive necrosis. As a result, a combination of streaking, brittleness, and leaf dropping could be seen in August with no mottling evident in the plants, and were it not for the wrinkling present, such plants would have been considered by anyone without access to previous records as being affected only with streak. Furthermore, at one time it was possible to arrange the streaked hills in a series with complete gradation from a mottled-streaked condition to a typically streak condition. It seems possible that this change and gradation from mosaic to streak was due in part to the presence of two viruses—rugose mosaic and streak, in part to variation in the time of infection (or to variation in diffusion of the virus), and in part to the increase in maturity of the plants. However, in this and similar cases, it is also possible that a single virus (rugose mosaic) produces streaking and leaf dropping in the conditions described. At any rate, correct diagnosis and the early removal of diseased hills seemed difficult under such conditions.

RESPONSE TO ENVIRONMENTAL FACTORS

Environment influences both the symptoms and the rate of spread of degeneration diseases. New symptoms following the transferring of a given lot to another region can not be regarded as the effect of the new environment unless either there is evidence that there was no new infection during the last season in the first region, or a similar part of the stock is kept in the first region as a control. Loss of symptoms following

such translocation may be considered as a result of masking by the ne[illegible] environment, unless they are masked by new symptoms of a seco[illegible] disease.

Tubers of a mosaic lot were divided and part of each tuber was plan[illegible] in northeastern Maine and part in Colorado (*45, p. 250*). During [illegible] same season, mottling was distinct in the part in Maine and absent in [illegible] the other. A similar lot was divided likewise and grown partly in nor[illegible] eastern Maine and partly at Washington, D. C. (*45, p. 250*), and duri[illegible] the same season mottling was distinct in Maine but doubtfully asce[illegible] tained in many hills at Washington. In three successive seasons [illegible] number of partly mosaic lots were divided and grown partly in nort[illegible] eastern Maine and partly in southwestern Maine (*45, p. 250*). Usual[illegible] the part of a lot grown in the southwestern area showed much le[illegible] mottling than the other part, while the reverse never was noted. Re[illegible] covery of the mottled appearance followed the return of a part to th[illegible] northeastern area.

In 1922, a similar test on the effect of different climatic conditions [illegible] plants from the same tuber was conducted with 30 Bliss Triumph tube[illegible] and with an equal number of Green Mountain tubers apparently havin[illegible] mild mosaic. A seed piece from the same tuber was planted in each [illegible] these localities: Presque Isle, Me.; Riverhead, Long Island, N. Y.; an[illegible] Norfolk, Va. Observations were made by the same person, one of th[illegible] writers, in the three localities. The results of these observations indi[illegible] cated that mottling was less distinct on the foliage at Norfolk than i[illegible] the other localities. It was also noted that most of the vines in th[illegible] three localities showed mild mosaic symptoms; a few plants plainly dis[illegible] closed mosaic-dwarf or bad mosaic symptoms. However, mosaic dwarf appeared on the plants from the same tuber in each of the thre[illegible] localities and no tuber produced plants having mild mosaic in one localit[illegible] and a different stage of mosaic in another locality. It appears tha[illegible] the difference in climatic conditions here as in the preceding tests chiefl[illegible] produced a difference in the distinctness of the mottling, the stage o[illegible] type of mosaic remaining the same.

Progeny of Green Mountain curly dwarf hills were grown partly in [illegible] warm room (approximately 67° F. or 19° C.) in the Orono greenhouse i[illegible] 1919–20, and partly in a cool room (approximately 56° F. or 13° C[illegible] Mottling appeared, was mostly restricted to the tissues along the vein[illegible] and was so restricted more in the warm room. The same was true o[illegible] progeny of mosaic hills selected in the same lot. Such a hill grown in th[illegible] open is shown in Plate 15, A.

In 1919 a stock of Green Mountains with about 80 per cent mosai[illegible] was grown on a number of fertilizer plots. Both the percentage of mosai[illegible] plants and the distinctness of mottling in those mosaic were reduce[illegible] somewhat during the first part of the season by high-nitrogen and high[illegible] potash fertilizers.

In 1919 four mosaic tubers were split in two and one-half of each wa[illegible] planted under an insect cage in the field and the other in the open. I[illegible] two cases the caged hills were more distinctly mottled than the corre[illegible] sponding uncaged ones.

Twelve tubers from Bliss Triumph mosaic hills were grown in th[illegible] Orono greenhouse in 1920–21. They were split in two, and one half o[illegible] each was planted in a warm place (approximately 75° F. or 24° C. mea[illegible] temperature) and the other half in a cool place (approximately 60° F[illegible] or 16° C. mean temperature). Wrinkling and mottling were more marke[illegible]

the cool place (Pl. 15, C). When partly grown, the plants in the warm place were put near the others in the cool place. Then the difference failed to continue in the upper parts of the plants, since the leaves that expanded upon the transferred plants were like the corresponding leaves of the plants kept in the cool place from the first. This experiment confirms one of those performed by Freiberg (*16, p. 195–202*), in which potato and other plants showed apparent recovery from mosaic under certain conditions of temperature. Murphy has described the seasonal masking of mosaic symptoms (*30, p. 148*), and Johnson has demonstrated the suppressing effects of temperatures over 20° C. (*19*).

Ten whole tubers from a leaf-roll stock were planted in the Orono greenhouse during the winter of 1921–22. Three of the 10 plants were grown caged, and of these three, two showed no distinct rolling, though all three were chlorotic and burned. The uncaged plants were rolled until after the roof was whitewashed in April, after which new leaves that grew out were only chlorotic and flat. This diminishing of rolling was noted also under field cages in 1921. Such an effect from caging or other means of shading is not surprising in view of the evidence that leafroll is associated with the abnormal accumulation of food, which is caused by the more constant internal symptom of phloëm necrosis (*38, p. 43–45*), probably only in the presence of sufficient sunlight.

In 1921 tubers from hills diseased in 1920 were split in two and the halves of each tuber were planted, respectively, under and outside of insect cages. The disease in 1920 was either streak, curly dwarf, or mosaic, and several varieties, including Green Mountains and Rurals, were used. The summer was warm and dry, so that the cheesecloth cover probably caused changes in environmental factors as shown by Burns for wire-screen cages (*9*). Comparisons were made several times during the season. The hills grown outside of cages usually were smaller than the inclosed sister hills. The shading in the cages enlarges healthy plants so that this difference in diseased plants is not surprising. Such a difference in size is not due to different degrees of dwarfing so much as to the same degree of dwarfing acting upon plants of different sizes. In a few cases mottling was present in the cages while the chlorosis outside was diffused. Symptoms observed in common to these environments were wrinkling (in Green Mountains), ruffling (in Rurals and Green Mountains), brittleness (in certain seedling varieties), burning (in seedlings, Rurals, and Mountains), and premature death (in seedlings). This experiment indicates that a reduction in sunlight may decrease the apparent dwarfing effect of a disease and may increase mottling. It also shows that in certain climatic conditions burning is not prevented by shading or by protection from insects provided certain diseases are present.

In 1920 parts of the same stock of a strain of the Green Mountain variety were planted in two fields in northeastern Maine and in a field on Long Island. The yield rate in one field in Maine was almost double that in the other and but little more than that on Long Island. The mosaic percentage was low. Another part originally of the same strain but all-mosaic was planted in the poor field in Maine and in the Long Island field. Its yield rate was lower on Long Island, even with field conditions twice as good for healthy stock. Thus an all-mosaic condition reduced the yield rate of Green Mountains much more on Long Island than in northeastern Maine. Stewart reports heavy losses upon Long Island (*46, p. 357*). Murphy describes the effects of season, locality, and climate on the yield-rate reduction by leaf roll (*29, p. 40–44*) and mosaic (*29, p. 67*).

In addition to mosaic symptoms being masked or modified by regional differences in weather and climate, there are differences between regions in regard to the amount of degeneration diseases and the rate of their spread in commercial fields. This is shown by local observations and by comparing representative lots from different regions when grown in the same place. Differences are apparent in three groups of lots from three counties of New York (*1, p. 11*). The writers have reported a difference between different parts of Maine with mosaic spreading less in the St. John River Valley where aphids were less numerous (*41, p. 75*). This difference disappeared in 1921 with a heavy infestation of aphids in that valley, as is described in connection with certain data on isolation (Table XXVIII, field 38). Similar regional differences have been described by Murphy (*29, p. 35–36, 59 67*) and Quanjer (*39, p. 143*).

The second-generation plants to the lots grown in Maine and Long Island, as noted in a foregoing paragraph (p. 101), were grown again in Maine, where the chief difference between these lots consisted in a higher percentage of leaf roll in the Long Island stock than in the duplicate Maine lots, which had no leaf roll.

In 1921 a Green Mountain lot grown in Maine in 1920 was divided into five parts, which were planted, respectively, between mosaic Bliss Triumph rows in northeastern Maine and in southern Maine, between Irish Cobbler leaf-roll rows in these two places, and on Long Island between Green Mountain rows both all-mosaic and 25 per cent leaf roll (Table XXVI). In 1922 the Long Island part when grown in northeastern Maine was 60 per cent mosaic and 75 per cent leaf roll, while at the same place the other stocks showed less disease (Table XXVI). Similar exposure to leaf roll and mosaic at the two Maine stations was made in 1921 with a Bliss Triumph lot and an Irish Cobbler lot, and a comparison in 1922 in northeastern Maine showed that a slightly greater spread of mosaic had occurred in northeastern Maine and a markedly greater spread of leaf roll in southern Maine (Table XXVI).

TABLE XXVI.—*Spread of mild mosaic and leaf roll in three places*

Variety.	Location in 1921.	Disease in 1922.	
		Mosaic.	Leaf roll.
		Per cent.	*Per cent.*
Green Mountain	On Long Island between Green Mountain rows 100 per cent mosaic and 25 per cent leaf roll.	62	75
	In southern Maine between mosaic rows	31	0
	In northern Maine between mosaic rows	57	0
	In southern Maine between leaf-roll rows	40	50
	In northern Maine between leaf-roll rows	40	3
Bliss Triumph	In southern Maine between mosaic rows	44	0
	In northern Maine between mosaic rows	56	0
	In southern Maine between leaf-roll rows	26	10
	In northern Maine between leaf-roll rows	55	8
Irish Cobbler	In southern Maine between mosaic rows	0	0
	In northern Maine between mosaic rows	2	0
	In southern Maine between leaf-roll rows	2	14
	In northern Maine between leaf-roll rows	23	4

RESULTS OF TESTS OF CONTROL MEASURES

With the preceding data in mind, tests of various control measures can be made and interpreted more intelligently. Seed treatment seems useless, since the plant juice containing the contagium can not well be poisoned. Heat does not injure the virus before injuring the tuber (8, *19*). The only apparent solution is the selection of noninfected seed by one or more of the methods which will be discussed.

TUBER SELECTION

The selection of hills and strains is in the broad sense a type of tuber selection, but the term "tuber selection" is used here as meaning the selection of tubers in the bin without knowledge as to the health of the parent plant. The elimination of tubers with net necrosis of a certain type will reduce the amount of severe leaf roll in the progeny (*41*). Discarding tubers with the spindling-tuber symptoms (produced by plants in the second year of infection) will reduce the amount of third-year infection of the spindling-tuber and unmottled curly-dwarf diseases. (First-year infection in field occurs late and does not show in vines or tubers.) The use of only the largest potatoes will reduce the amount of third-year infection of mosaic and leaf roll (*41, p. 76–77*). However, there will probably always be tubers of good size and shape that were produced by plants infected the previous year or before and that are perpetuating disease, unless the field producing the crop was free from infection.

With the spindling-tuber disease it is possible to eliminate a large percentage of the spindle-shaped or "run long" tubers and so reduce the percentage of this disease. However, tuber selection alone, even with the spindling-tuber disease, does not necessarily result in eliminating this malady, since many of the normal-shaped tubers will be infected, due to late season transmission by aphids in the field. Also, symptoms are not always conspicuous (Pl. 9, C).

Selection of normal-shaped tubers from a Green Mountain and an Irish Cobbler lot from 1917 to 1922 did not produce stock free from spindling tuber. In fact, the Irish Cobbler lot showed over 90 per cent spindling tuber in 1922, or an increase of about 90 per cent in six seasons. Although the conditions for field infection in this lot, being grown near diseased stock in experimental plots, were very favorable, nevertheless this indicates that tuber selection alone does not insure freedom from this malady.

With the spindling-tuber disease then, as with other insect-borne diseases of the potato, the futility of attempting control by means of tuber selection alone is very evident from the results of insect transmission.

HILL SELECTION

In 1918 hills were selected as healthy, both next to mosaic hills and also with varying numbers of healthy hills between them and the nearest mosaic hill in the same row, and those next to diseased hills produced more mosaic progeny than the others (*40, p. 334*). In 1919 Green Mountain hills that apparently were healthy were dug in two places at progressively later dates in the season. One set was secured at the Presque Isle laboratory plots and consisted of 50 hills each grown in

the row next to a mosaic hill. The other was obtained at Aroostook Farm in a rogued plot about 15 meters from the nearest unrogued mosaic hills. In each place 10 hills were dug on each of five dates—August 2, 11, 20, 30, and September 9. The progeny of the five groups of hills were mosaic respectively in 67, 68, 70, 89, and 93 per cent in the laboratory stock and in 0, 7, 0, 2, and 26 per cent in the farm stock. Therefore, in the laboratory hills, next to mosaic ones, there was a high percentage of mosaic infection by August 2 and probably only chance escaping of inoculation prevented all hills from becoming diseased by August 30. In the farm plot, 15 meters from mosaic hills, there was little infection until September 9, and then much less than at the laboratory. The two sets of hills were not only of the same variety but to a large extent of the same strain. Evidently, proximity to mosaic hills greatly increased infection, apparently through easier dispersal by virulent insects. The small amount of infection that occurred at the farm and that was manifested chiefly in the last harvest probably was due to virulent insects, soil and other factors appearing to be negligible as possible causes.

An experiment parallel to the preceding consisted in removing one tuber from every one of 30 hills in each of the two places on each date except the last, when every hill was dug usually with more than one tuber. The results were the same except that the percentage of infection generally was higher. Another parallel experiment consisted in selecting apparently healthy hills next to mosaic ones in a field, at the farm, that contained Green Mountain plants with 80 per cent mosaic. One hundred pounds of tubers were dug on August 7, and a like quantity again on September 8. The progeny of the two lots were, respectively, 46 and 84 per cent mosaic. These results are similar to those of the series of harvests made at the laboratory.

In 1920 conditions of uncontrolled field transmission were presumably varied by the selection of hills at different times and at different places on the same farm. The data are presented in Table XXVII.

In field A, proximity to mosaic hills increased the amount of infection and proximity to leaf-roll hills was necessary for infection. The sudden increase of infection from the August 12 harvest to that of August 23 is to be explained as follows: In this field certain recommended methods of spraying for aphid control were being tested and meanwhile the approximate number of aphids was determined and recorded frequently. About 95 per cent of these insects were potato aphids (*Macrosiphum solanifolii* Ashm.). These were present by July 17, increased most rapidly during the second week in August until there were over 2,000 to a plant on the average, and decreased rapidly and disappeared during the third week in August mostly because of a fungus disease that followed the inception of a period of cloudy, humid weather. The aphids of the other species (determined as *Aphis sp.* by Dr. Edith M. Patch), were extremely localized on occasional plants, being apparently slow in dispersing. Presumably, the greatest dispersal of aphids occurred about August 13, when they were most numerous and when the second harvest of tubers was completed. Apparently the high level of tuber infection was reached by August 23, in the healthy hills adjacent to diseased ones, indicating a 10-day period to be necessary for diffusion of the virus to the tubers if the chief cause of infection were the potato aphids. This is the time for such diffusion as shown on page 97. The

fact that leaf roll did not reach the tubers in hills adjacent to leaf-roll hills in this field until after August 13, and then only in small amount, may be due to the greater difficulty of effective leaf-roll inoculation compared with mosaic, or to slower diffusion of the virus in the plant, or to both.

TABLE XXVII.—*Mosaic and leaf roll uncontrolled inoculations in the field in 1920*[1]

Location in 1920[2]	Series.[3]	Hills.	Progeny, 1921. Tuber units.	Progeny, 1921. Mosaic.	Progeny, 1921. Leaf roll
				Per cent.	*Per cent.*
In field A, next to mosaic hills	1-A	10	39	3	0
	1-B	10	42	5	0
	1-C	10	42	69	0
	1-D	10	44	48	0
In field A, next to leaf-roll hills	2-A	10	41	2	0
	2-B	10	43	9	0
	2-C	10	38	16	0
	2-D	10	38	18	18
In field A, in healthy plot	3-A	10	41	0	0
	3-B	10	48	6	0
	3-C	10	42	0	0
	3-D	10	39	15	0
In field B (rogued), next to sites of rogued hills	4-A	10	42	0	0
	4-B	10	40	13	0
	4-C	10	45	7	0
	4-D	10	31	19	0
In field B, not next to sites of rogued hills	5-A	10	42	0	0
	5-B	10	44	2	0
	5-C	10	44	5	0
	5-D	10	37	0	0
In field C, next to mosaic hills	6-A	10	48	8	0
	6-B	10	47	17	0
	6-C	10	47	15	0
In field C, not next to diseased hills	7-A	10	44	5	0
	7-B	10	47	13	0
	7-C	10	45	16	0
Irish Cobblers in field C, next to leaf-roll hills	8-A	5	25	16	0
	8-B	5	24	42	0
	8-C	5	19	5	0
	8-D	5	25	20	0
Irish Cobblers in field C, not next to leaf-roll hills	9-A	5	25	4	0
	9-B	5	22	18	0
	9-C	5	23	0	0
	9-D	5	25	4	0
In field D (rogued), on soil in which mosaic plants grew in 1919.[4]	10-A	10	49	2	0
	10-B	10	48	0	0
	10-C	10	47	6	0
	10-D	10	43	5	0
In field D, on soil in which healthy plants grew in 1919	11-A	10	41	0	0
	11-B	10	47	2	0
	11-C	10	47	2	0
	11-D	10	44	7	0

[1] Green Mountains except for Series 8 and 9.
[2] Except for field D, with 2 years elapsing with no potatoes grown on the soil.
[3] Each series consists of subseries according to the dates of harvesting, which are, respectively, July 29–30 (A), Aug. 12–13 (B), Aug. 23–24 (C), and Sept. 15 (D).
[4] No volunteers present because all tubers in the soil were killed by a severe winter with snowfall light in the early part.

In fields B and D, which were rogued of diseased hills as soon as the symptoms were observed, the small amount of infection found by August 12 may be the result of insect transmission occurring before the roguing was performed. A comparison of Series 3, 10, and 11 shows that as much mosaic may be contracted by plants in a healthy plot in the same field with mosaic plants and plots as by plants grown on soil that supported a mosaic plot the year before (*40, p. 335–36*). A comparison of Series 1 and 6 shows that considerable mosaic infection reached the tubers of hills next to diseased hills by August 13 in one field, but not in the other, and a comparison of Series 2 and 8 shows that it was only in the former field that leaf-roll infection reached the tubers of hills next to diseased hills by September 15. The former field was about three times as far as the latter from the nearest known winter host of the potato aphids (*36*) and possibly became infested later or to a less extent, or both.

In 1921 hill selections were made in two Irish Cobbler fields containing, respectively, 5 and 15 per cent of hills producing spindling tubers, and in a Green Mountain field containing 1 per cent. The results, given in Table III, indicate that hill selection was useless for eliminating disease, though it reduced the increase otherwise occurring without hill selection. It is not surprising that hill selection in a field containing disease is often disappointing. Murphy (*29, p. 45–47*) and Quanjer (*39, p. 142*) have had the same experience. When as low as 5 per cent of diseased hills may contaminate the majority of the healthy hills in the same field, the hill-selection method clearly has limitations.

REMOVAL OF DISEASED HILLS

The removal of diseased hills, or roguing, is in the broad sense a method of hill selection. It differs from hill selection in the strict sense chiefly by using healthy hills after removing the diseased hills that may serve as sources of infection, whereas the latter uses healthy hills that have been more or less exposed to infection throughout the season. The effectiveness of roguing is determined by several factors. Correct diagnosis, thoroughness at each inspection, complete removal of each rogued hill from the field, and several inspections at the proper times are necessary.

Roguing with no insect spraying and with no great degree of isolation has been tested for several years, 1917–20, by the writers (*45, p. 270; 40, p. 332; 41, p. 77*). With variations according to the season and degree of proximity to diseased plots, the general results have been to keep the amount of mosaic in the stock about the same from year to year, between 13 and 30 per cent, except that roguing in 1920 was followed in 1921 by 35 per cent and 65 per cent in Green Mountains and Bliss Triumphs. This was a gain over conditions in unrogued parts of the same strains. Why the removal presumably of all diseased hills has not eliminated the disease, or at least steadily decreased the percentage, is not certain. Possible causes are masking of symptoms at the time of roguing, dispersal of transmitting insects from rogued plants before or after these plants are pulled and insect dispersal from unrogued plots.

Roguing accompanied by isolation from unrogued diseased stock and by insect spraying will be considered later.

TABLE XXVIII.—*Effect of proximity on healthy and diseased potatoes*

Field.	Sample.	History of good stock. 1921 Variety.	Location of sample in field.	Disease.	Aphids.	1922 Mosaic.	History of near-by potato field. 1921 Variety.	Mosaic.	Distance from good stock.	Direction from good stock.
				Per cent.		*Per cent.*		*Per cent.*	*Meters.*	
31	1	Green Mountain	Northeast	Less than 1 mosaic		0				
	2	do	East	do		0				
	3	do	Southeast	do		8				
	4	do	North	do		26		10–15	70–170	North, east, and northeast.
	5	do	Center	do		3	Green Mountain			
	6	do	South	do		0		(1)	100	Northwest.
	7	do	Northwest	do		0				
	8	do	West	do		0				
	9	do	Southwest	do		0				
34	1	do	Northeast	do		0				
	2	do	East	do		0				
	3	do	Southeast	do		0				
	4	do	North	do		0	Irish Cobbler	1+	(2)	On west and south.
	5	do	Center	do		0	Rose 4	10	(2)	North.
	6	do	South	do		8	Green Mountain	98	70	Do.
	7	do	Northwest	do		0				
	8	do	West	do		0				
	9	do	Southwest	do		19				
37	1	do	North	4 mosaic	8 on 5 leaves.	0				
	2	do	North center	do	do	8	Green Mountain	38	60	South.
	3	do	Center	do	do	16	Irish Cobbler	(3)	(2)	East. West.
	4	do	South center	do	do	0				
	5	do	South	do	do	7				
38	1	do	Northwest	4 in American Giant volunteer plants; none in Green Mountain.	Abundant	7				
	2	do	West	do	do	32				
	3	do	Southwest	do	do	58				
	4	do	North	do	do	56	Bliss Triumph	40	(4)	All sides of field.
	5	do	Center	do	do	14				
	6	do	South	do	do	9				
	7	do	Northeast	do	do	1				
	8	do	East	do	do	46				
	9	do	Southeast	do	do	17				

[1] High. [2] Adjacent. [3] Apparently healthy. [4] Adjacent; healthy field only 12 meters wide.

TABLE XXVIII.—*Effect of proximity on healthy and diseased potatoes*—Continued

Field.	Sample.	History of good stock. 1921. Variety.	Location of sample in field.	Disease.	1922. Aphids.	1922. Mosaic.	History of near-by potato fields. Variety.	1921. Mosaic.	Distance from good stock.	Direction from good stock.
				Per cent.		*Per cent.*		*Per cent.*	*Meters.*	
4[illegible]	1	Green Mountain	Northeast corner	Less than 1	13 on 5 leaves.	1	Rose 4	(5)	(6)	Northwest corner.
	2	do	Southeast corner	do	do	1	Irish Cobbler	(5)	(7)	East of southeast corner.
	3	do	Middle	do	do	13	do	(5)	(8)	Southwest.
	4	do	Northwest corner	do	do	4	Green Mountain	66	100	Southwest corner.
	5	do	Southwest corner	do	do	66				
43	1	do	Northeast corner	Trace in field	3 on 5 leaves.	9	do	2	20	Northeast.
	2	do	Middle	do	do	0	Irish Gem	12		
	3	do	Southwest	do	do	0				

[5] Apparently none. [6] Across road. [7] Across railroad. [8] Adjacent.

SELECTION AND ISOLATION OF HEALTHY STOCKS

It is possible to find fields that are healthy, either absolutely or comparatively. Then it becomes important to know what to expect of such fields under known conditions of isolation from diseased stocks, and what to do with stock from such fields to maintain the existing state of health. Usually when healthy stocks are secured by potato growers they are planted in such a way in relation to diseased stocks that there is a chance to study the effects of proximity rather than of isolation, so that proximity will be considered here also.

The results of planting rows of healthy stock alternating with mosaic stock have been described on page 102. In 1918 and 1919 rows of Irish Cobbler plants contracted more leaf roll next to leaf-roll rows than when farther removed (*41, p. 76–77*). As in the mosaic experiments, the effects of the various factors, such as contact, soil, and virulent insects, can not be distinguished. Murphy has disclosed the spreading of mosaic and leaf roll across several rows in various parts of Canada (*29, p. 47–51, 64–65*). Krantz and Bisby state that mosaic dwarf spreads rapidly in Minnesota (*21, p. 19–22*).

In 1920, two Green Mountain fields with less than 1 per cent mosaic were observed. One was small, consisting of four rows, and was planted about 30 meters distant from four rows of diseased Irish Cobblers that came from a farm where all degeneration diseases are present. In 1921, about 10 per cent of the hills were diseased, with leaf roll, mild mosaic, rugose mosaic, leaf-rolling mosaic, and spindling-tuber disease. Some disease appeared even in volunteers from tubers left in the field before these were destroyed by chewing insects. The other field was large, and was planted about 50 meters distant from an American Giant field with 24 per cent of the hills mosaic. Samples and bulk stock from this field contained less than 1 per cent again in 1921.

Two growers in southern Maine isolated very healthy Green Mountains sufficiently in 1921 for the stock in 1922 (seen by the writers) to have less than 1 per cent disease, one grower giving the distance of isolation as about one-fourth mile.

In 1921, the writers selected samples in several fields planted with healthy stock and located at different distances from fields planted with diseased stock. During the growing season observations on the percentage of diseased plants as well as on the aphid infestation were made. Peck samples were harvested from different parts of each field. These were planted in 1922 and readings on the percentage of mosaic were taken. Further data on these observations are presented in Table XXVIII.

The results in Table XXVIII disclose that the mosaic percentage increased in each of the stocks and that the greatest increase obtained in field 38, where no hill was farther than 6 meters from Bliss Triumphs having 40 per cent mosaic and where there was a heavy aphid infestation. The stock in field 42 happened to be the one described previously as being 50 meters distant from mosaic American Giants in 1920 and as showing less than 1 per cent mosaic in 1921. Apparently, the location and other conditions of this stock were more favorable for infection with mosaic in 1921 than they had been in 1920, for one sample gave progeny with 66 per cent, and the bulk stock of this field showed 15 per cent mosaic in 1922. The results in this table show that mosaic sometimes spreads very readily from diseased to adjacent healthy lots, that prox-

imity and heavy aphid infestation together increased the spread of mosaic and that with greater isolation than obtained in these fields it may be possible to maintain stock mosaic free if once the disease is eliminated. Isolation of a half mile in England has prevented infection while proximity increased it (*10, 30*).

INSECT CONTROL

Aphids have proved to be effective transmitting agents in a number of the experiments described in this paper. Although it may not be possible to control aphids sufficiently to prevent transmission in the field in all times and places, it at least is necessary unless there is no disease present. There are two distinct phases of the problem of insect control in relation to disease transmission. The presence of transmitting insects in a partly diseased field is to be expected to result in late-season infection of healthy hills that can not be distinguished and that therefore can not be eliminated in the current season. In a healthy field the mere presence of insects is harmless in relation to disease, but the dispersal of transmitting insects to either kind of field from a wholly diseased field is undesirable. In some situations it may be possible to prevent interhill transmission before removing the diseased hills and yet be impossible to prevent new contamination from other fields, while in other situations it may be possible to prevent interfield transmission and yet be impossible to avoid an infestation that causes interhill transmission.

In endeavoring to follow the recommendation of entomologists regarding aphid control, the writers have formed the opinion that spray methods reported to be effective in more southern regions, at least in preventing directly injurious infestations, are not so useful in preventing transmission in northeastern Maine. In this region high-ridge culture is practiced, so that many leaves lie on the surface of the soil and support aphids that can not be touched by the spray and that are a permanent source of infestation. Also, the tops in healthy fields grow so large that they form an expanse of foliage through which it is often impossible to walk without stepping over plants and in which it is difficult to drag undershot nozzles and to use them effectively for covering the leaves. Expensive applications of nicotine solution in 1921 reduced aphids in two four-row sections in a seed plot containing 19 such sections. The seed plot was rogued of about 10 per cent of the diseased hills, partly after aphids were present, and these two sections had progeny with about 9 per cent diseased as compared with from 15 to 18 per cent for the rest of the seed plot. The same methods used again in 1922 were effective in killing all aphids except on the leaves next to the soil. The seed plot of 1922 was a half mile further from rose bushes than the seed plot of 1921, and the potato aphids arrived about two weeks later than at the site of the 1921 plot, following roguing of all mosaic hills. The progeny in 1923 will indicate the value of isolation of potatoes from rose bushes (*36*) in reducing the spread of mosaic and the value of the spraying in reducing the spread of the spindling-tuber disease. The latter could be rogued only in part of the seed plot planted by tuber units.

In 1918, several tubers from healthy Bliss Triumph hills grown in cages were selected to begin a strain grown in insect-proof cages in the following seasons of 1919 to 1922. Every tuber from this caged stock has produced healthy plants. These cages were located in the field near potatoes with high percentages of mosaic and leaf roll, and during the same period

uncaged Bliss Triumph stock of the same original strain as the caged plants grown in the same locality increased from 15 to 84 per cent mosaic. Similar observations were made by Krantz and Bisby (*21, p. 18–19*). That the protective effect of caging is due to insect exclusion rather than to its modification of climatic factors is shown by the many cases described previously of infection within cages by introducing virulent insects.

In this connection it is interesting to note that Murphy (*31*) finds that capsid bugs and jassids transmit leaf roll of potato in Ireland, where those insects apparently are more important in this respect than aphids. Elmer (*13*) reports successful cross inoculations by transferring mealy bugs (*Dactylopus* sp.) from mosaic infected Solanum and cucurbit plants to healthy cowpea (*Vigna catjang*) seedlings. Such observations confirm the general assumption that possibly a number of different insects may be found which transmit these diseases.

GENERAL CONCLUSIONS

In addition to a subsequent summary including the various facts demonstrated in this paper, two general conclusions may be pointed out, relating, respectively, to the rôle of diseases in the degeneration of potatoes and to the general influence of region on the degeneration-disease problem.

"Running-out" is generally recognized as relating to plants which for various reasons fail in the maximum production. Unfavorable soil and weather conditions, senility, reversion, and loss of vigor due to prolonged asexual reproduction are some of the causes to which degeneration in plants has been ascribed. While such factors as favorable soil and climate undoubtedly play a very effective rôle in the proper development of plants, it must also be recognized from the comparatively recent investigations on degeneration diseases in plants that no matter how favorable the conditions for development, a diseased plant will be less productive than a healthy one of the same species and variety in the same environment.

Perhaps in no other plant has the theory of senescence been so frequently mentioned as with the so-called degeneration or deterioration of the potato. Abnormalities due to mosaic, leaf roll, and spindling tuber heretofore have frequently been ascribed to the asexual reproduction of the potato. In view of the recent findings regarding the nature and infectiousness of these maladies, it is no longer necessary to mention senility in connection with them, as pointed out by Cotton (*10, p. 163–164*). When one realizes that a large percentage of healthy plants exists in many of the potato varieties propagated asexually for many years, one questions rather seriously whether senescence plays any rôle whatsoever. In this connection, as Cotton (*10, p. 164*) has pointed out, many of our most persistent weeds continue to reproduce very successfully almost entirely through asexual reproduction.

The evidence on the presence and importance of degeneration diseases of the potato also shows that a knowledge of the pathological significance of an abnormal condition of a plant is as necessary as a knowledge of its cultural or genetic relations, if reliable deductions are to be drawn (*10, p. 164*).

Furthermore, it is apparent that these degeneration diseases must be recognized in any authentic comparison of strains of potatoes in the

same variety. It is possible that differences in performance between strains of the same variety result from varying percentages of these degeneration diseases and not merely from other variations, such as vigor, as is frequently designated. Disease-free strains of the same variety should be grown under absolutely uniform conditions for several seasons in order to permit accurate testing of the supposed inherent differences between strains of a variety.

Regarding the general effect of the region the various experiments detailed in this paper tend to show that the potato degeneration problem is similar in the northeastern United States to the same problem in other parts of America (including Canada) and in parts of Europe (including the British Isles). It is a complex problem, involving several diseases that react differently to transmission agents, varieties, and other environmental factors. While this general similarity is true, it is also true that the problem because of its complexity may vary greatly from one locality to another. It follows then that control measures must be worked out for different sets of conditions, following research based initially on the general principles now fairly well understood.

Two examples may be given of striking differences between regional problems. These may or may not be referable fundamentally to climate bearing in mind that the preference given to varieties in a given region or the prevalence of insects transmitting a disease may be determined by climate. The presence of the spindling-tuber disease in at least five widely separated States of this country, with its apparent absence from Europe, is a difference that, regardless of its cause, complicates the situation because of the elusiveness of vine symptoms. The presence of net necrosis as a tuber symptom of leaf roll in at least two States of this country and in Japan also is a feature that has not been noted in Europe. A third difference, consisting of the successful development and use of a leaf-mutilation method of inoculation in at least three parts of this country may disappear when the method is tried in other countries (p. 54). In view of such differences and the differences reported for parts of the same country, the effectiveness of certain control measures in one region can not be trusted as a reliable indication of their usefulness in another region.

With the degeneration problem showing somewhat different aspects in one region from another, with seed being transported from northern to southern regions to reduce injury from degeneration, and with the need for the use of all scientific results, it is desirable that it at least be possible to identify a given degeneration disease in different places. This is not yet possible because of the modifying effects of climate and variety upon the symptoms, and because of the variation of climate and varietal preference from one region to another. Growing parts of the same tuber, with many tubers, and in different regions, is helpful but not always practicable. Undivided tubers are not reliable for comparison unless they are produced under conditions where no infection of the parent vines is possible. Great usefulness is in store for methods that will readily identify the yet unknown causal agencies, whether organism or compounds, of the several diseases, somewhat as phloëm-necrosis microanalysis has been used by Quanjer (*39, p. 132–37*) to detect an apparently consistent symptom of leaf roll. Furthermore, it is quite apparent that the identification of the causal agencies, whether by analysis or by culture, will ultimately result in an authentic classification of the so-called virus diseases.

SUMMARY

(1) Degeneration diseases of potatoes, in the absence of known identifying causes, are symptom complexes whose elementary unit symptoms can and should be determined in the same standard variety or varieties and in the same environment.

(2) Research with these diseases is developing a somewhat distinct technic and terminology.

(3) In the Green Mountain variety, several degeneration diseases have been distinguished and transmitted—namely, mild mosaic, leaf-rolling mosaic, rugose mosaic, streak, leaf roll, spindling-tuber disease, and unmottled curly dwarf.

(4) In Green Mountains, mild mosaic was not transmitted by contact except in stem and tuber grafts.

(5) A leaf-mutilation method of inoculation has certain advantages over other methods. In Green Mountains this method transmitted mild mosaic, with the effectiveness increased by insect-cage or greenhouse conditions as compared to open-field conditions, by inclosure within a damp chamber, and by repetition.

(6) In Green Mountains aphids (*Macrosiphum solanifolii* Ashmead) transmitted mild mosaic, both alone and in combination with leaf roll and with spindling tuber, while negative results were secured with flea beetles (*Epitrix cucumeris* Harris) and Colorado Potato beetles (*Leptinotarsa decemlineata* Say.).

(7) In Green Mountains, aphids from plants with a "curly-dwarf" combination apparently consisting of leaf-rolling mosaic and spindling tuber together, transmitted the curly-dwarf combination to part of a hill and spindling tuber alone to the other part, distinction being made between different tuber units of the second generation.

(8) Leaf-mutilation inoculation transmitted both rugose mosaic and streak readily in Green Mountains.

(9) Leaf roll was transmitted neither by contact except in grafts, nor by leaf-mutilation inoculation.

(10) Spindling-tuber disease is characterized, and proofs given of its being a degeneration disease, spreading in the field, being perpetuated by the tubers (shown in part by mechanical measurements), and being transmitted by tuber grafts, stem grafts, leaf mutilation, and aphids.

(11) Unmottled curly dwarf was transmitted by leaf-mutilation inoculation and by aphids.

(12) Combinations of symptoms exist that include more than one degeneration disease in the same plant. Aphids sometimes transmit only one disease from such a plant, but more often transmit the combination.

(13) In Irish Cobblers, leaf roll was transmitted by grafting and by aphids but not by leaf-mutilation inoculation, which is successful with all other degeneration diseases tested.

(14) In New White Hebrons in 1921, leaf-roll and net-necrosis percentages increased with the average weight of the tubers.

(15) Leaf-mutilation inoculation of Green Mountains in 1920 effected intervarietal transmission of rugose mosaic, a combination of leaf-rolling mosaic and spindling tuber, and unmottled curly dwarf, but was ineffective with mild mosaic and leaf roll. Comparison inoculations with aphids with four of the sources of inoculum gave similar results, transmitting rugose mosaic to Green Mountains from curly-dwarf plants in the Rural group.

(16) Leaf-mutilation inoculation of Green Mountains in 1921 effected intervarietal transmission of streak, rugose mosaic and streak together, rugose mosaic, leaf-rolling mosaic, and mild mosaic in insect cages (uncontrolled in the open field), but not leaf roll. With spindling tuber (uncontrolled in the open field) present in the progeny, leaf-rolling mosaic having been transmitted formed a curly-dwarf combination. Rugose mosaic was thus transmitted from Carman No. 3 (Rural group) to Rural New Yorker, and from this and two seedling varieties to both Green Mountains and Irish Cobblers, but the symptom complexes were not identical in any two varieties.

(17) Streak did not appear the same before and after tuber perpetuation.

(18) Comparison inoculations with juice in capillary glass tubes were much less effective than leaf mutilation, with rugose mosaic and streak.

(19) Aphid inoculations of Green Mountains in 1921 effected intervarietal transmission of leaf-rolling mosaic from curly-dwarf plants in three varieties of the Rural group, of unmottled curly dwarf and spindling tuber (separately) from Irish Cobblers, of rugose mosaic from one seedling variety, and of leaf-rolling mosaic and rugose mosaic together from two seedling varieties. Aphids also transmitted rugose mosaic to Irish Cobblers from two seedling varieties.

(20) Leaf-mutilation inoculations of Green Mountains in 1922 resulted in current-season symptoms of streak, rugose mosaic and streak combined, and rugose mosaic with and without streaking. Comparison inoculations with mild mosaic, leaf roll, and spindling tuber gave no current-season symptoms in the open field. Comparison inoculations under insect cages gave current-season symptoms with mild mosaic and spindling tuber. Several different symptom complexes yielded only rugose mosaic as the current-season effect of inoculation, sometimes with rugose mosaic somewhat masked in the original complex. Results with Green Mountains were somewhat duplicated in Irish Cobblers and Bliss Triumphs, but some varietal modification of symptoms apparently occurred in these and seedling varieties.

(21) In greenhouse inoculations, transmission of mild mosaic from Bliss Triumphs to Green Mountains was effected to some extent with juice in capillary glass tubes, but not with immersion of a split stem in diseased juice. It was effected more readily with leaf mutilation as the number of inoculated leaves was increased, and more readily with aphids as the number of individual insects was increased, being possible with one individual aphid.

(22) In greenhouse leaf-mutilation inoculations, rugose mosaic was transmitted from a seedling variety to Green Mountains and from Green Mountains to Irish Cobblers, but leaf roll was not transmitted from Irish Cobblers to Green Mountains.

(23) Interspecific inoculations with leaf mutilation and aphids indicate that tobacco mosaic is not identical with potato mild mosaic, that tomato is susceptible to both of these mosaics and also to potato rugose mosaic, and that nightshade (*Solanum nigrum* L.) is susceptible to potato mild mosaic. Raspberry mosaic seems harmless to potatoes.

(24) The various degeneration diseases of potatoes are different as to their economic importance resulting from their distribution and effect upon yield rate and quality.

(25) Natural transmission by insects contributes to the difficulty of the control problem.

(26) Perpetuation occurs in tubers and not in soil alone.

(27) About 10 days were required for the mild mosaic virus to diffuse from inoculated leaves to the tubers.

(28) Mosaic plants from the same seed tubers sometimes show different symptom complexes in different environments. Mottling is suppressed by southern regions and by higher temperatures. Dwarfing of the tubers, and therefore reduction of yield rate, was more pronounced in a southern region.

(29) Shading tended to increase mosaic mottling and decrease leaf rolling.

(30) In duplicate plots leaf roll and mosaic were contracted by healthy lots growing between rows of diseased lots, more in some regions than others.

(31) Selection of tubers without knowledge of the parent plants can not eliminate seed from diseased plants infected late the preceding season.

(32) The digging of selected healthy hills progressively later in the growing season was correlated with greater numbers of aphids and with greater amounts of disease in the progeny.

(33) Hill selection in fields containing diseased plants throughout the growing season is disappointing as a means of eliminating disease, but sometimes gives better results than using unselected stock from the same field.

(34) Proximity and a heavy aphid infestation increased the spread of mild mosaic, while sufficient isolation from diseased stocks reduced it so that a state of freedom from the disease was maintained. Isolation by 30 meters was insufficient, and over 400 meters was sufficient.

(35) Conditions that reduced aphid dispersal from diseased to healthy hills also reduced the amount of disease transmission.

(36) Potato degeneration is largely, and possibly is entirely, a result of the increase of, and injury by, certain degeneration diseases.

(37) The potato degeneration-disease problem is on the whole similar for all potato-growing regions, but is complex enough to vary somewhat from one region to another.

LITERATURE CITED

(1) ANONYMOUS.
1919. MOSAIC DISEASE AS A FACTOR INFLUENCING YIELD. *In* Potato Mag., v. 2, no. 5, p. 11, 27.

(2) ALLARD, H. A.
1914. THE MOSAIC DISEASE OF TOBACCO. U. S. Dept. Agr. Bul. 40, 33 p., 7 pl.

(3) ——
1917. FURTHER STUDIES OF THE MOSAIC DISEASE OF TOBACCO. *In* Jour. Agr. Research, v. 10, p. 615–632, pl. 63.

(4) ATANASOFF, D.
1922. STIPPLE-STREAK DISEASE OF POTATO. Meded. Landbouwhoogeschool Wageningen, deel 24, verhandel. 5, 32 p., 5 pl.

(5) BARRUS, M. F.
1917. PHYSIOLOGICAL DISEASES OF POTATOES. *In* 9th Ann. Rpt. Quebec Soc. Prot. Plants, 1916–17, p. 45–53, 3 fig.

(6) ——
1918. POTATO-MOSAIC AND CERTIFIED SEED. *In* Potato Mag., v. 1, no. 4, p. 13–14.

(7) —— and CHUPP, Charles C.
1922. YELLOW DWARF OF POTATOES. *In* Phytopathology, v. 12, p. 123–132, 1 fig., pl. 7–8.

(8) BLODGETT, F. M.
1922. THE RELATION OF TIME AND TEMPERATURE TO THE KILLING OF POTATOES AND POTATO MOSAIC VIRUS. (Abstract.) *In* Phytopathology, v. 12, p. 40.

(9) BURNS, G. P.
1921. TIP-BURN AND THE LEAFHOPPER. (Abstract.) *In* Phytopathology, v. 11, p. 56–57.

(10) COTTON, A. D.
1922. THE SITUATION WITH REGARD TO LEAF-CURL AND MOSAIC IN BRITAIN. *In* Roy. Hort. Soc. Rpt. Internat. Potato Conf., 1921, p. 153-166.

(11) DOOLITTLE, S. P., and WALKER, M. N.
1922. NOTES ON CUCURBIT MOSAIC. (Abstract.) *In* Phytopathology, v. 12, p. 42-43.

(12) EDGERTON, C. W., and TIEBOUT, G. L.
1921. THE MOSAIC DISEASE OF THE IRISH POTATO AND THE USE OF CERTIFIED POTATO SEED. La. Agr. Exp. Sta. Bul. 181, 15 p., 3 fig.

(13) ELMER, O. H.
1922. MOSAIC CROSS-INOCULATION AND INSECT TRANSMISSION STUDIES. *In* Science, n. s., v. 56, p. 370-372.

(14) FOLSOM, Donald.
1920. POTATO MOSAIC. Me. Agr. Exp. Sta. Bul. 292, p. 157-184, fig. 28-30. Bibliographical footnotes.

(15) ———
1921. POTATO LEAF-ROLL. Me. Agr. Exp. Sta. Bul. 297, p. 37-52. fig. 26-35. Bibliographical footnotes.

(16) FREIBERG, George W.
1917. STUDIES IN THE MOSAIC DISEASES OF PLANTS. *In* Ann. Mo. Bot. Gard., v. 4, p. 175-226, pl. 14-17.

(17) GILBERT, Alfred H.
1922. THE CORRELATION OF FOLIAGE-DEGENERATION DISEASES OF THE IRISH POTATO WITH VARIATIONS OF THE TUBER AND SPROUT. (Abstract.) *In* Phytopathology, v. 12, p. 40.

(18) IWANOWSKI, D.
1903. ÜBER DIE MOSAIKKRANKHEIT DER TABAKSPFLANZE. *In* Ztschr. Pflanzenkrank., Bd. 13, p. 1-41, pl. 1-3.

(19) JOHNSON, James.
1922. THE RELATION OF AIR TEMPERATURE TO THE MOSAIC DISEASE OF POTATOES AND OTHER PLANTS. *In* Phytopathology, v. 12, p. 438-440, 1 fig.

(20) KASAI, Mikio.
1921. OBSERVATIONS AND EXPERIMENTS ON THE LEAF-ROLL DISEASE OF THE IRISH POTATO IN JAPAN. *In* Ber. Ohara Inst. Landw. Forsch., Bd. 2, Heft 1, p. 47-77. Literature cited, p. 76-77.

(21) KRANTZ, F. A., and BISBY, G. R.
1921. RELATION OF MOSAIC TO RUNNING-OUT OF POTATOES IN MINNESOTA. Minn. Agr. Exp. Sta. Bul. 197, 31 p., 18 fig. References, p. 29-31.

(22) KUNKEL, L. O.
1921. A POSSIBLE CAUSATIVE AGENT FOR THE MOSAIC DISEASE OF CORN. *In* Bul. Exp. Sta. Hawaiian Sugar Planters' Assoc., v. 3, no. 1, p. 44-58, 2 fig. Literature cited, p. 58.

(23) ———
1922. AMEBOID BODIES ASSOCIATED WITH HIPPEASTRUM MOSAIC. *In* Science. n.s., v. 55, p. 73.

(24) McKINNEY, H. H., ECKERSON, Sophia H., and WEBB, R. W.
1923. INTRACELLULAR BODIES ASSOCIATED WITH THE ROSETTE DISEASE OF WHEAT. (Abstract.) *In* Phytopathology, v. 13, p. 41.

(25) ——— ——— ———
1923. INTRACELLULAR BODIES ASSOCIATED WITH A "MOSAIC" OF HIPPEASTRUM JOHNSONII. (Abstract.) *In* Phytopathology, v. 13, p. 41-42.

(26) MATZ, J.
1919. INFECTION AND NATURE OF THE YELLOW STRIPE DISEASE OF CANE (MOSAIC, MOTTLING, ETC.). *In* Jour. Dept. Agr. Porto Rico, v. 3, no. 4, p. 65-82, 11 fig.

(27) MELHUS, I. E.
1922. MOSAIC STUDIES. (Abstract.) *In* Phytopathology, v. 12, p. 42.

(28) MILLER, Justus.
1919. NORTHERN ONTARIO SEED POTATO TRADE. *In* Potato Mag., v. 1, no. 11, p. 5, 33-34, illus.

(29) MURPHY, Paul A.
1921. INVESTIGATION OF POTATO DISEASES. Canada Expt. Farms Div. Bot. Bul. 44, ser. 2, 86 p., 35 fig. Literature cited, p. 83-86.

(30) MURPHY, Paul A.
1922. SOME RECENT WORK ON LEAF-ROLL AND MOSAIC. *In* Roy. Hort. Soc. Rpt. Internat. Potato Conf., 1921, p. 145-152, 2 fig.

(31) ———
1922. LEAF-ROLL AND MOSAIC, TWO IMPORTANT DISEASES OF THE POTATO. *In* Dept. Agr. and Tech. Instr. Ireland Jour., v. 22, p. 281-284, 2 fig.

(32) ORTON, W. A.
1914. POTATO WILT, LEAF-ROLL, AND RELATED DISEASES. U. S. Dept. Agr. Bul. 64, 48 p., 16 pl. Bibliography, p. 44-48.

(33) ———
1920. STREAK DISEASE OF POTATO. *In* Phytopathology, v. 10, p. 97-100, 1 fig., pl. 8.

(34) PALM, Björn T.
1922. DE MOZAIEKZIEKTE VAN DE TABAK EEN CHLAMYDOZOONOSE? Bul. Deliproefstation Medan-Sumatra no. 15, 10 p. English résumé, p. 7-10.

(35) PARKER, R. C.
1919. TESTING SEED POTATOES ON LONG ISLAND. *In* Potato Mag., v. 2, no. 3, p. 8, 22-23; no. 4, p. 19, 27-28, illus.

(36) PATCH, Edith M.
1921. ROSE BUSHES IN RELATION TO POTATO CULTURE. Me. Agr. Exp. Sta. Bul. 303, p. 321-344, fig. 50. Literature cited, p. 344.

(37) ———
1922. AROOSTOOK POTATO INSECTS. *In* Jour. Econ. Ent., v. 15, p. 372-373.

(38) QUANJER, H. M.
1920. THE MOSAIC DISEASE OF THE SOLANACEÆ, ITS RELATION TO THE PHLOEM-NECROSIS, AND ITS EFFECT UPON POTATO CULTURE. *In* Phytopathology, v. 10, p. 35-47, 14 fig. Literature cited, p. 47.

(39) ———
1922. NEW WORK ON LEAF-CURL AND ALLIED DISEASES IN HOLLAND. *In* Roy. Hort. Soc. Rpt. Internat. Potato Conf., 1921, p. 127-145, 20 fig. Literature, p. 144-145.

(40) SCHULTZ, E. S., and FOLSOM, Donald.
1920. TRANSMISSION OF THE MOSAIC DISEASE OF IRISH POTATOES. *In* Jour. Agr. Research, v. 19, p. 315-338, p. 49-56.

(41) ——— ———
1921. LEAFROLL, NET-NECROSIS, AND SPINDLING-SPROUT OF THE IRISH POTATO. *In* Jour. Agr. Research, v. 21, p. 47-80, pl. 1-12. Literature cited, p. 78-80.

(42) ——— ———
1922. TRANSMISSION OF POTATO STREAK. (Abstract.) *In* Phytopathology, v. 12, p. 41.

(43) ——— ———
1923. A "SPINDLING-TUBER DISEASE" OF IRISH POTATOES. *In* Science, n. s., v. 57, p. 149.

(44) ——— ———
1923. SPINDLING-TUBER AND OTHER DEGENERATION DISEASES OF IRISH POTATOES. (Abstract.) *In* Phytopathology, v. 13, p. 40.

(45) ——— ——— HILDEBRANDT, F. Merrill, and HAWKINS, Lon A.
1919. INVESTIGATIONS ON THE MOSAIC DISEASE OF THE IRISH POTATO. *In* Jour. Agr. Research, v. 17, p. 247-274, pl. A-B (col.), 25-30. Literature cited, p. 272-273.

(46) STEWART, F. C.
1916. OBSERVATIONS ON SOME DEGENERATE STRAINS OF POTATOES. N. Y. (Geneva) Agr. Exp. Sta. Bul. 422, p. 319-357, 12 pl.

(47) ——— and SIRRINE, F. A.
1915. THE SPINDLING-SPROUT DISEASE OF POTATOES. N. Y. (Geneva) Agr. Exp. Sta. Bul. 399, p. 133-143, 3 pl.

(48) STUART, William.
1915. GROUP CLASSIFICATION AND VARIETAL DESCRIPTIONS OF SOME AMERICAN POTATOES. U. S. Dept. Agr. Bul. 176, 56 p., 19 pl. Reissued 1918, 59 p., 19 pl.

(49) TOLAAS, A. G.
1922. MINNESOTA POTATO CERTIFICATION RULES. *In* Potato Mag., v. 4, no. 9, p. 10, 18.

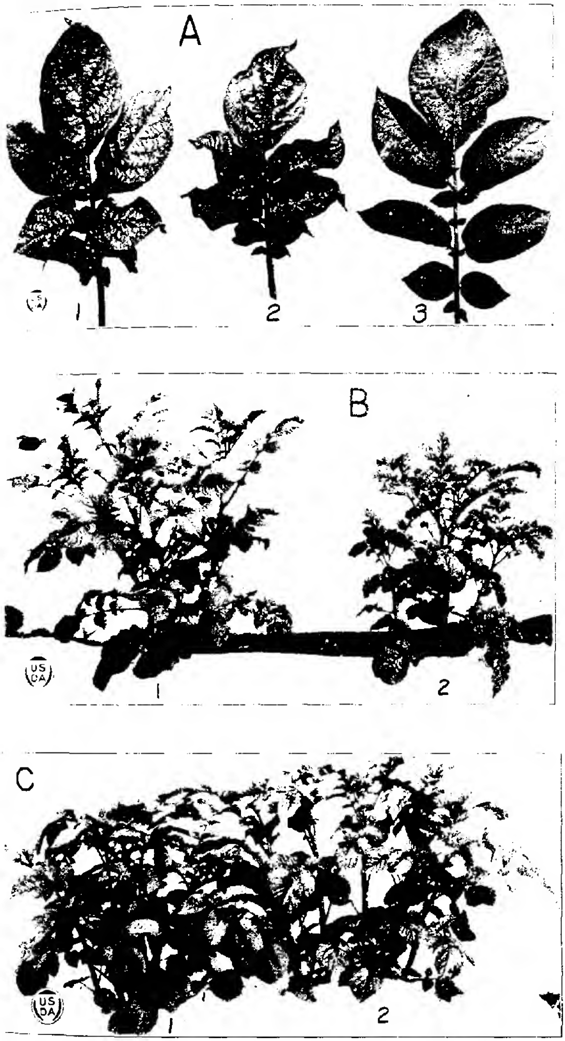
(50) WORTLEY, E. J.
1918. POTATO LEAF-ROLL: ITS DIAGNOSIS AND CAUSE. *In* Phytopathology, v. 8, p. 507-529, 16 fig.

PLATE 1

A.—(1, 2) Leaves from mosaic Green Mountain plant. (3) Leaf from healthy Green Mountain plant.

B.—(1) Mild mosaic Green Mountain. (2) Medium plus mosaic Green Mountain.

C.—(1) Healthy plant from half-tuber seed piece. (2) Mild mosaic plant from a half-tuber seed piece. Both from same hill of the preceding season. Green Mountain variety.


A
1
2
3
B
1
2
C
1
2

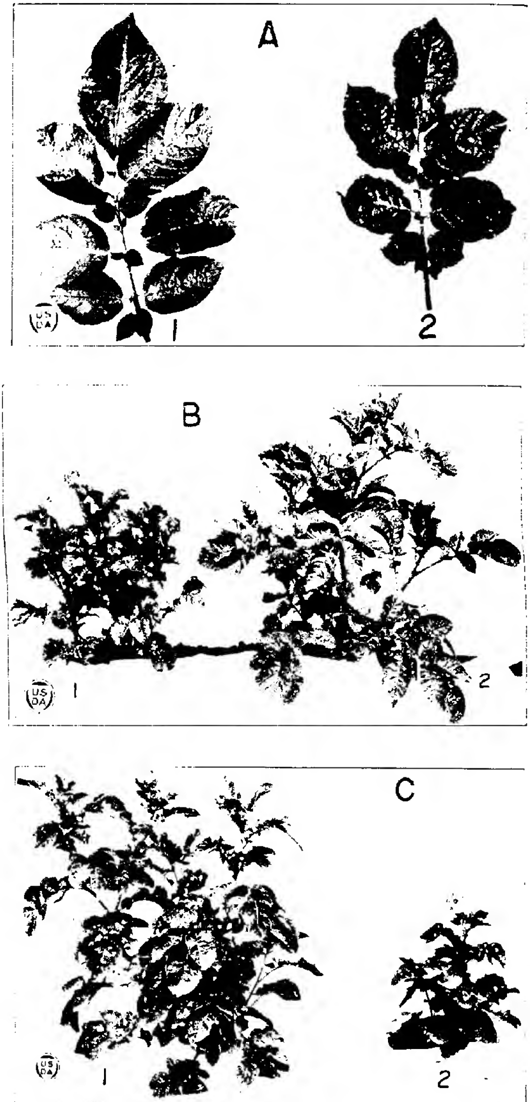

A
US DA
1
2
B
US DA
1
2
C
US DA
1
2

PLATE 2

A.—(1) Healthy leaf from vine from same tuber as inoculated plant also grown in cage. (2) Mild mosaic leaf from Green Mountain plant inoculated with inoculum from mild mosaic Green Mountain in cage.

B.—(1) Plant with leaf-rolling mosaic and spindling tuber, forming a curly-dwarf combination. (2) Leaf-rolling mosaic plant. Green Mountain variety.

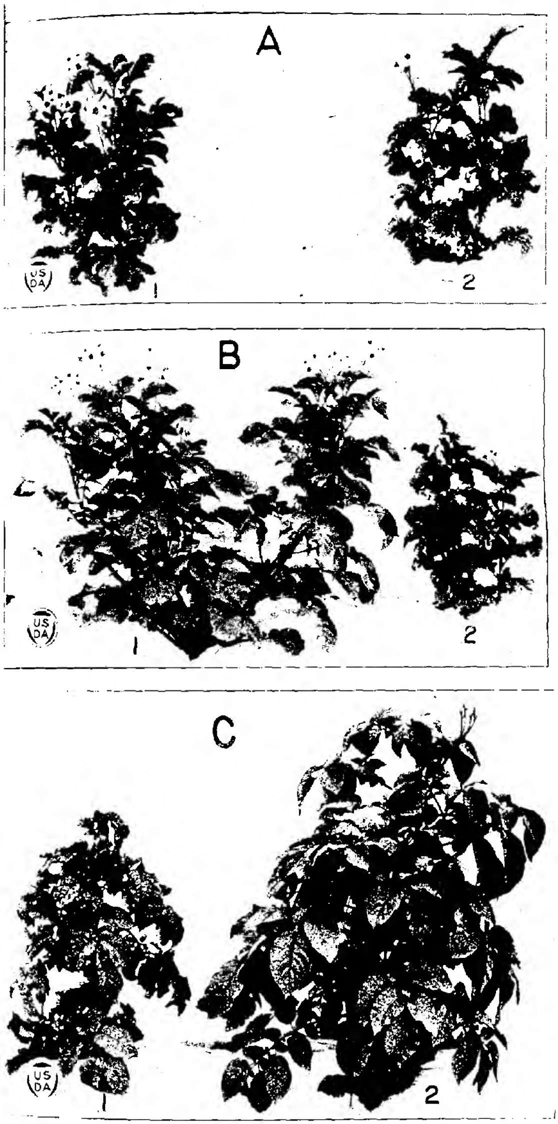
C.—(1) Leaf-rolling mosaic Green Mountain plant diseased as result of aphid inoculation in preceding season from parent of plant in C, 2. (2) Curly-dwarf plant of Uncle Sam variety (Rural group).

PLATE 3

A.—(1 and 2) Curly-dwarf Green Mountain. Source of inoculum for inoculati with aphids in cages in 1921. (Inoculated Green Mountain in B.)

B.—(1) Spindling-tuber vine from same 1921 hill as curly-dwarf plant, but infec with only one disease from the combination. (2) Curly-dwarf or spindling-tuber le rolling mosaic plant. Second generation to aphid inoculation in cages (source inoculum in A). Variety Green Mountain.

C.—Rugose mosaic and healthy Irish Cobbler vines. Mosaic plant is progeny fr vine apparently showing streak the previous season.


A
1
2
B
1
2
C
1
2

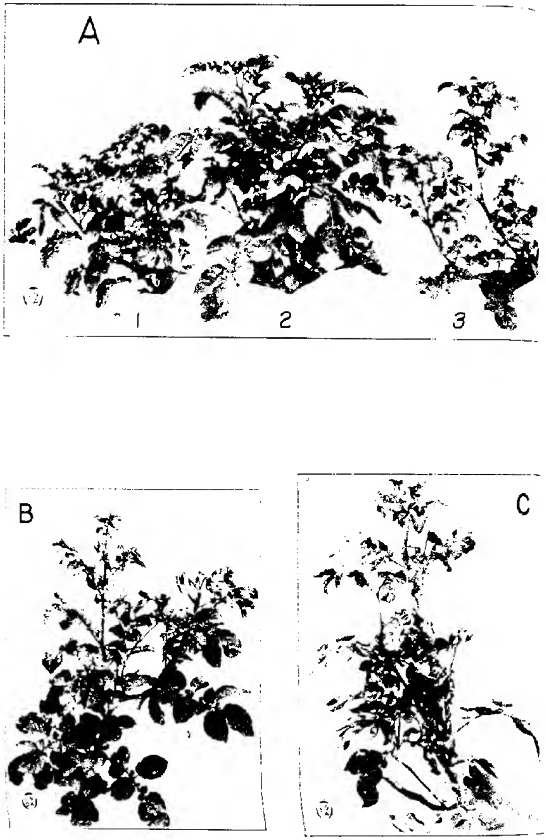

A
1
2
3
B
C

PLATE 4

A.—(1) Rugose mosaic Green Mountain produced by aphids dispersing from rugose seedling in cages. (2) Healthy Green Mountain from same 1921 hill as preceding infected plant. (3) Rugose mosaic seedling. Source of juice for aphid inoculation in cages.

B.—Rugose mosaic and streaking in top of plant. Variety Green Mountain.

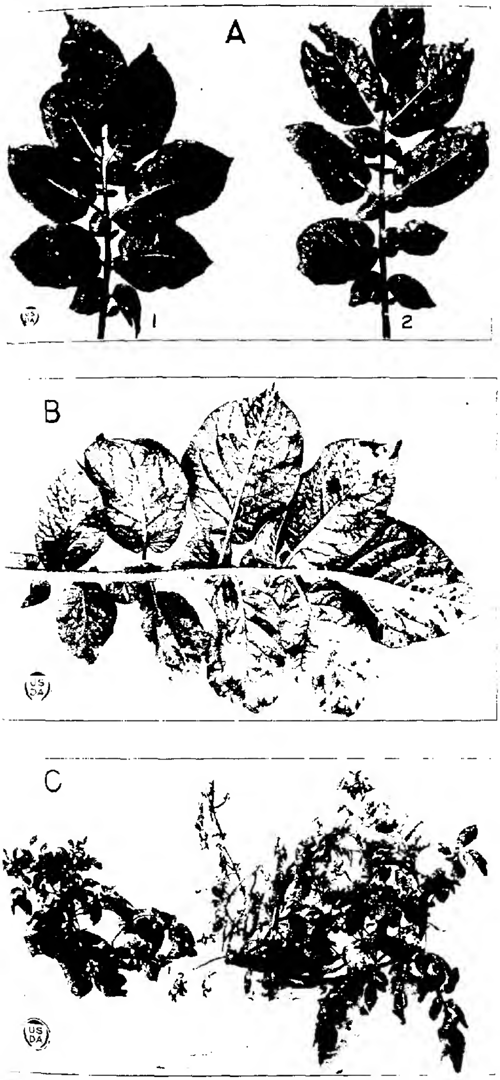
C.—Green Mountain plant healthy below, leaf dropping in middle, rugose mosaic above.

PLATE 5

A.—Leaves from Green Mountain plant inoculated with juice from streak seedling showing spotting, streaking, and burning. Some dead spots apparently spreading along veins producing a streaked appearance.

B.—Leaf of seedling with streaking, spotting, and burning of streak.

C.—Green Mountain plant showing streak resulting from leaf mutilation inoculation with juice from streak seedling when plant was about 15 cm. high. July, 1921.


A
1
2
B
C

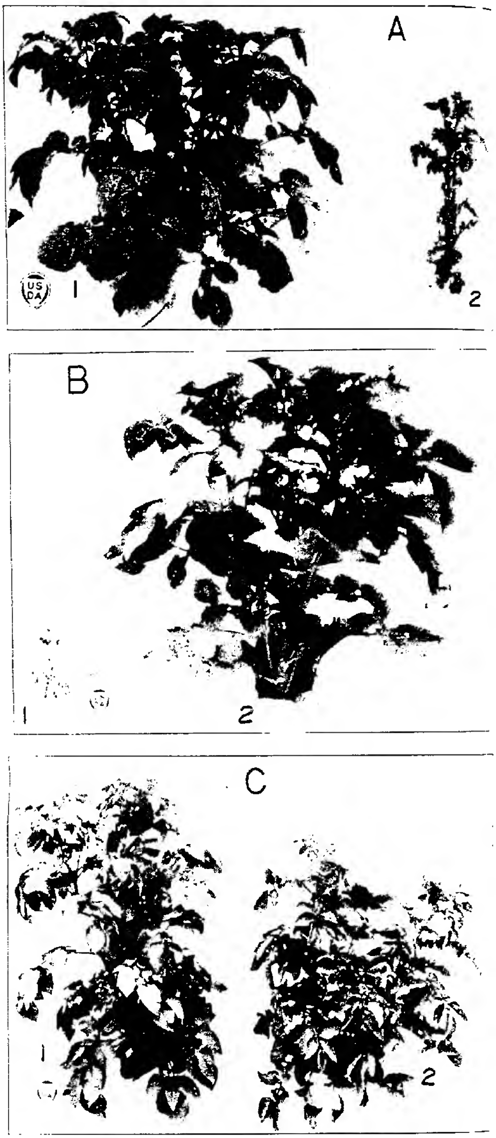

A
1
2
B
1
2
C
1
2

PLATE 6

A.—(1) Early stage of streak on seedling. (2) Mosaic dwarf on seedling.

B.—(1) Streak plant in second year of disease, progeny of plant in same series as that in Plate 5, C. (2) Healthy plant of control lot. Green Mountain variety.

C.—(1) Healthy hill. (2) Leaf-roll hill. These hills were in the same tuber unit.

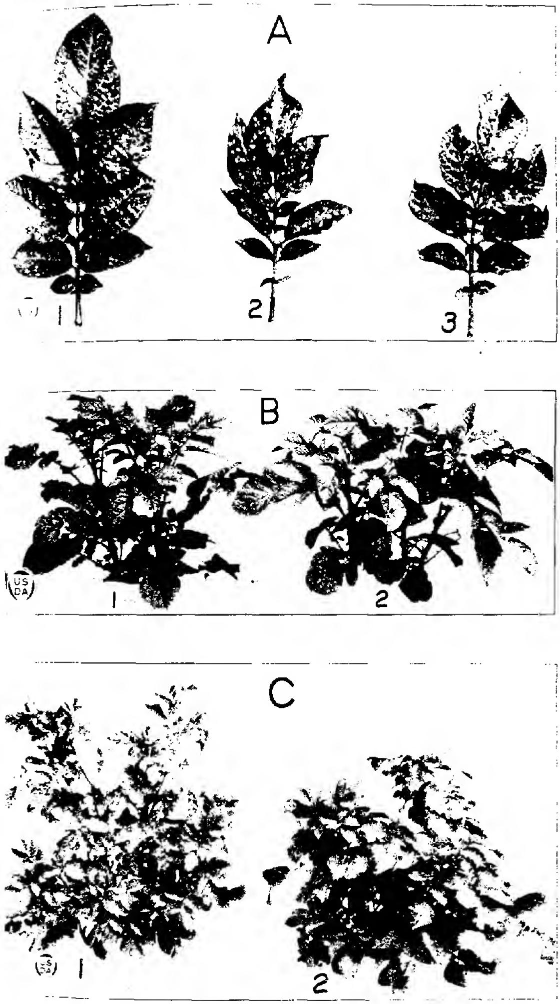
48108—23——6

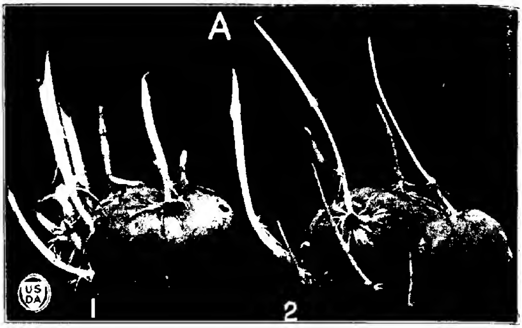
PLATE 7

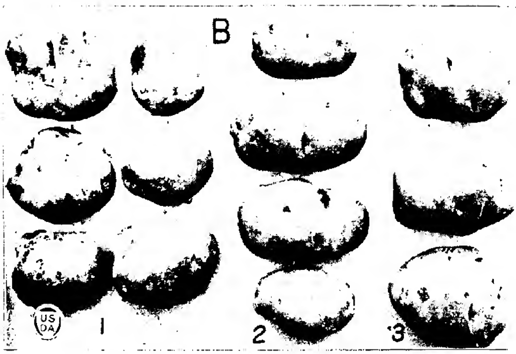
A.—(1) Top leaf from healthy Green Mountain. (2, 3) Top leaves from spindling-tuber Green Mountain. From plants of C (1, 2).

B.—(1, 2) Same hills as shown in C (1, 2), earlier in the season (July 6).

C.—(1) Spindling-tuber Green Mountain from half-tuber seed piece. (2) Healthy Green Mountain from quarter-tuber seed piece. Same hills as shown in B, but later in the season (August 29).


A
1
2
3
B
1
2
C
1
2


A
1
2


B
1
2
3

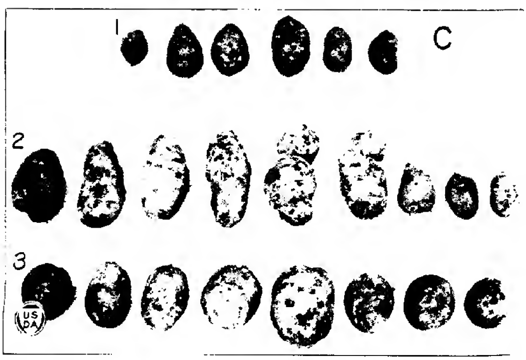

C
1
2
3

PLATE 8

A.—(1) Irish Cobbler tuber, normal shape, side view, after sprouting. (2) Irish Cobbler tuber, spindling-tuber shape, from same lot of seed.

B.—(1) Healthy Green Mountain, control to B, 2. (2) Spindling tuber in second generation as a result of growing in cage with aphids and spindling-tuber Irish Cobbler in first generation in 1921. (3) Spindling-tuber Irish Cobbler.

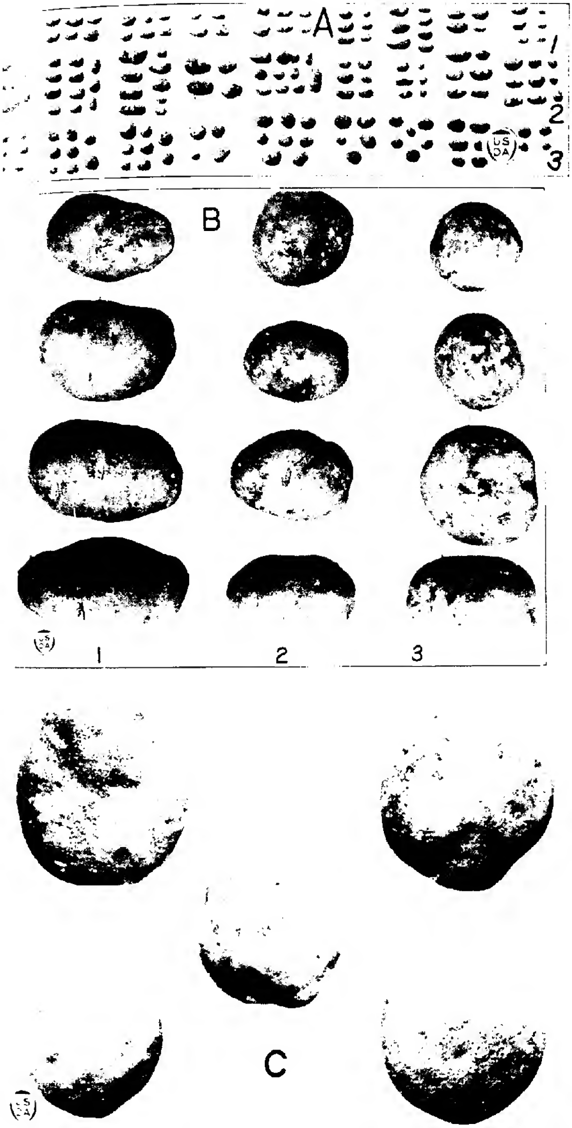
C.—(1) Six spindle-shaped tubers, progeny from the spindling tuber half grafted on the normal half tuber which produced the tubers shown in C, 2. (2) One hill spindling-tuber progeny from a normal half-tuber seed piece grafted on spindling tuber half-tuber seed piece. (3) Normal progeny from a quarter-tuber seed piece from the same tuber as the progeny in the middle row. Green Mountain variety.

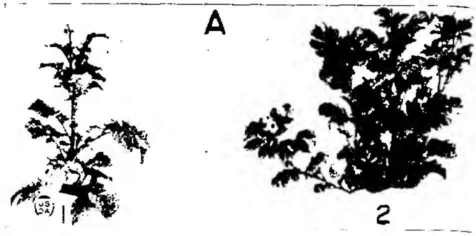
PLATE 9

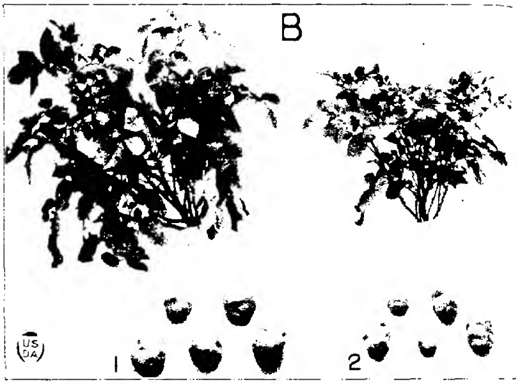
A.—Results of 10 of the spindling-tuber grafts. (1) Upper row, groups of tubers dug from 10 diseased hills grown from grafted half tubers originally diseased. (2) Middle row, groups of tubers dug from corresponding hills infected by grafting grown from grafted half tubers originally healthy. (3) Lower row, groups of tubers from 9 hills grown from ungrafted quartered parts of the same tubers producing the middle row; shape healthy.

B.—Results of leaf-mutilation inoculation in insect cage, 1922. (1) Tubers from spindling-tuber hill serving as source of inoculum; (2) tubers from inoculated hill with three tubers showing the disease; (3) tubers from uninoculated hill, control in same tuber unit as center hill but in different insect cage. Green Mountain variety. From stocks caged preceding year.

C.—Short tuber from spindling-tuber hill, with characteristic eyes and skin of the disease (center) and four tubers from healthy hills. Green Mountain variety.


A
1
2
3
B
1
2
3
C


A
1
2


B
1
2


C

PLATE 10

A.—(1) Dwarfed Irish Cobbler plant. (2) Unmottled curly-dwarf Green Mountain hill diseased as result of aphid inoculation in preceding season from parent of plant (A, 1).

B.—(1) Healthy plant and corresponding tuber progeny. (2) Plant and corresponding tuber progeny infected with spindling tuber. Healthy and diseased plants from Rose 4 variety.

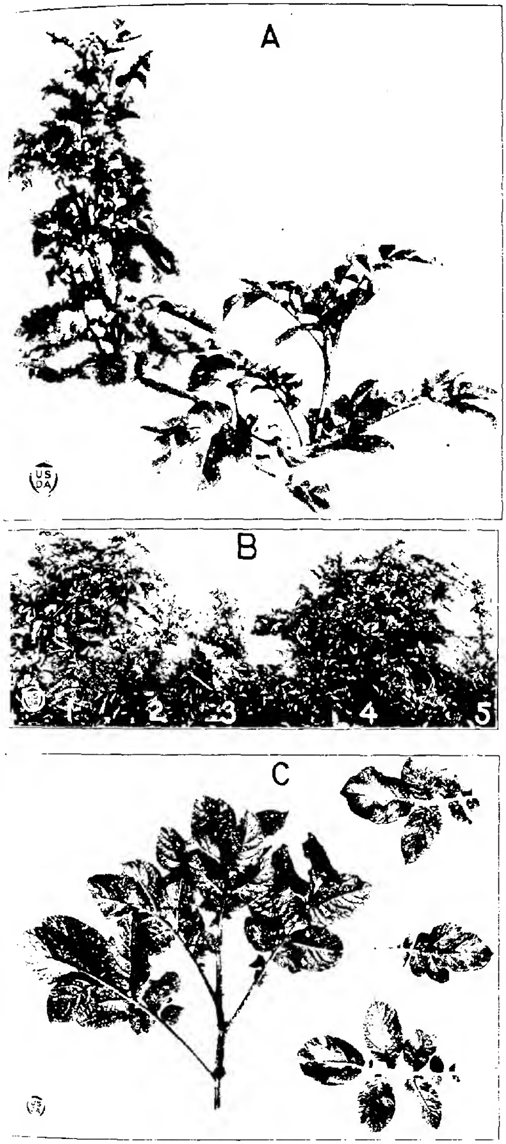
C.—Parts of the same Green Mountain strain. In left center, spindling-tuber seed potatoes planted. On right, all-mosaic seed potatoes planted. August 20, 1918.

PLATE 11

A.—Healthy branch on an unmottled curly-dwarf plant. Variety Green Mounta[illegible]

B.—(1, 4) Healthy, and (2, 3, and 5) unmottled curly-dwarf plants, variety Gre[illegible] Mountain. Infection produced in first generation by leaf mutilation with juice fr[illegible] unmottled curly dwarf Irish Cobbler.

C.—Foliage from Green Mountain plant showing streak.


A
B
1
2
3
4
5
C

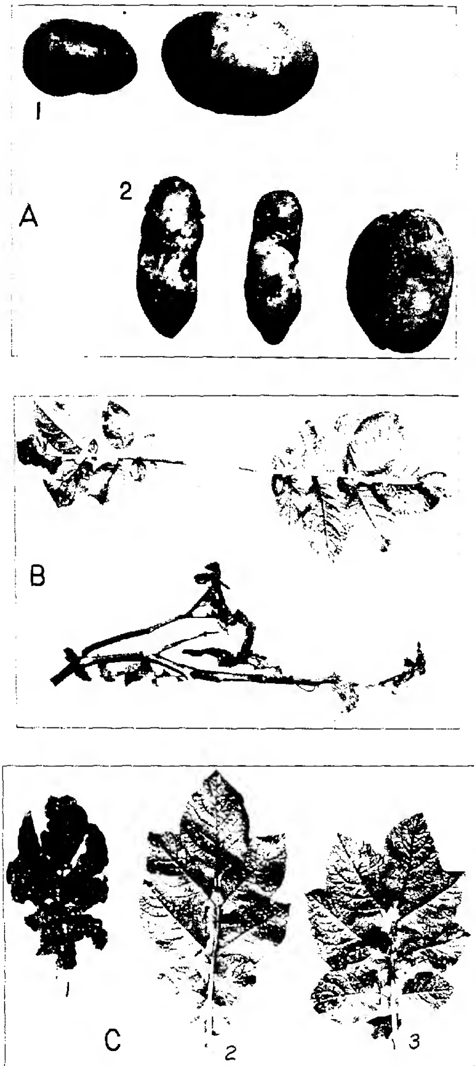

1
2
A
B
1
2
C
3

PLATE 12

A.—(1) Second-generation progeny to Green Mountain plant treated as A, 2. (2) Split tuber from Green Mountain plant inoculated by leaf mutilation with juice from unmottled curly-dwarf Green Mountain. The two somewhat spindle-shaped tubers are progeny from the split tuber.

B. Leaves from Green Mountain plant infected with streak; stem from unmottled curly dwarf Green Mountain plant, August 19, 1921.

C.—(1) Leaf from plant inoculated with juice from curly-dwarf Rural New Yorker. (2) Healthy leaf. (3) Leaf showing streaking. All leaves from Rural New Yorker variety.

PLATE 13

A.—Effects of recent leaf-mutilation inoculation, before appearance of disease symptoms.

B.—Capillary-tube inoculation with mosaic.


A


B

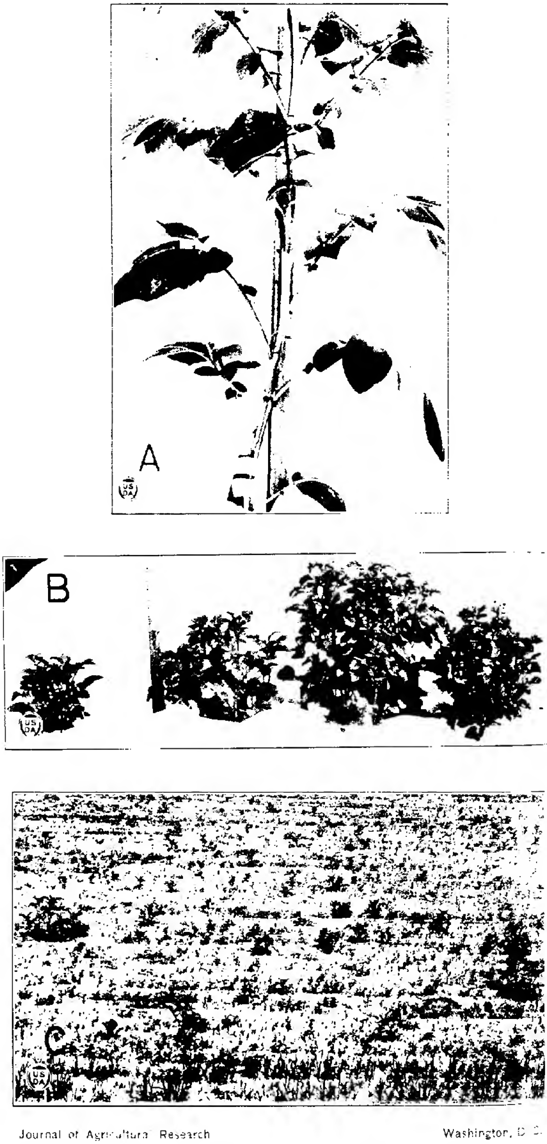

A
B
C

PLATE 14

A.—Stem-in-vial inoculation with mosaic.

B.—Four Irish Cobbler hills, July 6, 1922, each with spindling tuber. The two on the left have had it at least a year longer than the two on the right, as the former were planted with seed tubers showing the disease while the latter were planted with seed tubers appearing healthy. The two outside plants have leaf roll in addition.

C.—Volunteer potato plants in buckwheat. July 3, 1921, in northeastern Maine.

48108—23——7

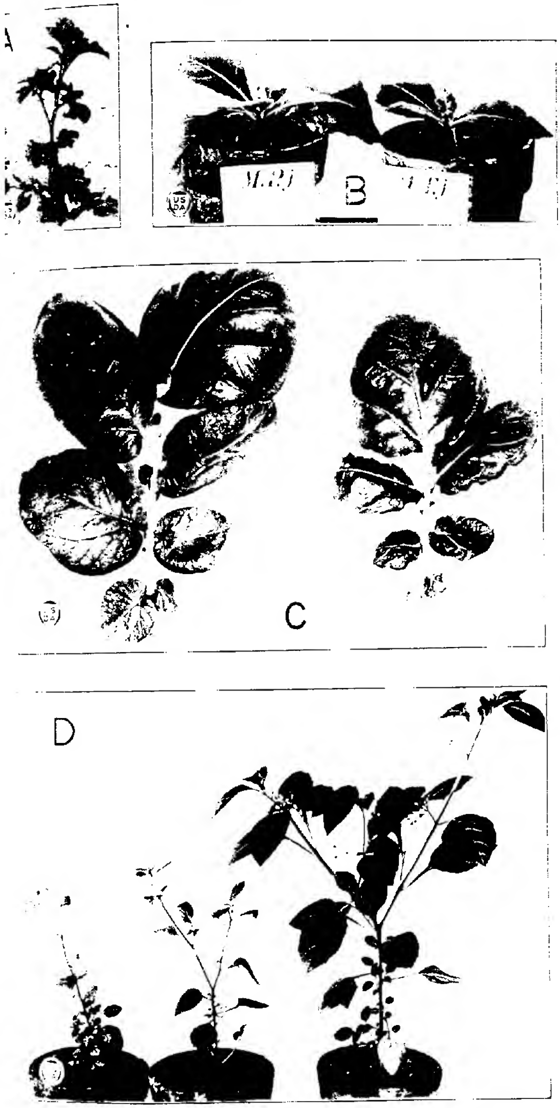
PLATE 15

A.—Green Mountain diseased plant representative of many that showed grea dwarfing and curling of the middle leaves than of the lowest or upper leaves, apparent as a result of certain weather conditions (July 2, 1921).

B.—(MTj) Tobacco plant inoculated 15 days previously and infected with jui from mosaic tobacco plant. (MPj) Tobacco plant of same seedling lot inoculated same way with juice from mosaic potato plant 26 days previously, but not becomi infected. Orono greenhouse, March 2, 1920. From series 6 and 12, respectively. Table XXI.

C.—Lower leaves of Bliss Triumph plants in same mosaic tuber unit. Larger le grown in warm room, smaller one in cool place. Wrinkling and mottling were m pronounced in cool place.

D.—Nightshade, *Solanum nigrum* L. On left, inoculated and infected with ju from a mosaic potato plant. In center, inoculated and infected with aphids from mosaic potato plant. On right, uninoculated healthy control from same lot. N that the lower leaves from the main stem are similar for the three plants, but th infection dwarfed the upper parts. Orono greenhouse, April 20, 1920.


B
C
D

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
10 CENTS PER COPY
SUBSCRIPTION PRICE, $4.00 PER YEAR

▽